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PREHARVEST FOLIAGE SPRAYS OF SUGARCANE WITH 2,4-D

M. A. Lugo-López and R. Grant[1]

Introduction

Sugarcane is the major cash crop of Puerto Rico. Crop net income, other factors being constant, depends on sugar yields and therefore, on cane tonnage and sucrose content. Considerable work has been done in an effort to increase yields through the use of better varieties, improved fertilizer practices, and adequate cultivation. However, the variability which can be observed in sugar yields is still rather large, with many extremely low levels. Although efforts have been directed towards finding the fundamental facts underlying the variations in sugar production, many gaps remain to be filled.

The possibility of increasing sugar yields through the use of hormones has been considered only lately (3).[2] The hormone most used, so far, has been 2,4-D (monohydrate dichlorophenoxyacetic acid). The use of 2,4-D and other hormones in lethal concentrations as herbicides in the early stages of the cane crop is a generalized practice in most Puerto Rican cane fields. Considerable progress has been made in recent years through research conducted locally and abroad, and centered mostly around the physiological action of the chemicals as weed-killers, their selective action upon various species of plants, movement in the soil, injurious effects to the crop, etc.

This paper reports on preliminary work conducted in Puerto Rico to test the effects of preharvest foliage sprays on sugarcane with 2,4-D on the final sucrose yields of the cane.

Theoretical Considerations

The purpose of this work was to obtain preliminary information on the influence of hormones on the sucrose content of the cane. An overdose of the selected growth regulator was used intentionally with the idea of

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[2] Numbers in parentheses refer to Literature Cited p. 193.

offsetting the metabolic processes of the sugarcane plant at a time approaching the harvesting season. It was hoped that such a change would result in the conversion of starches in the green leaf section of the stalk, and in the leaves, into sucrose, with a consequent increase in the final sucrose accumulation of the millable cane. About the time this work began, several reports appeared from abroad concerning the role of 2,4-D applications in relation to final sucrose accumulation (1, 2, 3).

Beauchamp (1) conducted various experimental trials followed by large-scale tests at different locations in Cuban plantations using 2,4-D to hasten the maturity of the sugarcane plant, using the varieties POJ 2878 and Media Luna 3/18. His reports indicate that dusting the cane foliage with 4 to 6 ounces to the acre of the sodium salt of 2,4-D produced a significant increase in sugar yields during the first 10 days following the application. Beauchamp reported increases in sucrose of 1.4 and 2.0 percent from the application of 2,4-D, 10 days prior to harvest. His results seem to be rather consistent considering the large area covered in his various experimental and large-scale trials. Almost invariably all treated plots yielded more sucrose than the control plots. Other reports from Louisiana and elsewhere have pointed to increased sucrose from 2,4-D applications (3). Loustalot, et al (2), from experimental work at Mayagüez, concluded that spraying M 336 sugarcane with 0.2-percent isopropyl ester of 2,4-D prior to harvesting had no significant effects on sugar yields. In view of these apparently contradictory reports concerning the role of 2,4-D on sugar yields and of the importance of the problem further work seemed necessary.

About the time that the preliminary work reported here was concluded, a report from Wort in British Columbia (4), indicated that increases of total sugars in the stem of buckwheat were obtained after applications of small, nonlethal concentrations of the ammonium salt of 2,4-D, 50, 100, 500, and 1,000 parts per million. Total sugars in the stems and leaves rose considerably within 1 day after the application, but fell again by the second day.

Experimental

Two fields were selected, one at the Solís farm of the Agricultural Experiment Station at Río Piedras and one at Colonia Mandry of the Eastern Sugar Associates, near Central Pasto Viejo at Humacao. Both fields have been planted to POJ 2878 and about 14 ratoon crops harvested following the original planting of cane. At Río Piedras the soil has been classified as Vega Alta clay loam, a rather extensive, level sugarcane soil of the north coastal region. At Humacao the soil was originally a muck at a very low level which had been reclaimed from the sea, and had undergone considerable mineralization. Both fields were divided into 6 blocks with 10

plots each. The area of the plots was about 0.01 acre and they were nearly square in shape. A row of cane was cut around each plot and 2 rows were left standing between every 2 plots to serve as buffer strips. Between each 2 plots there was a 20-foot separation. The row of cane eliminated around each plot provided a very convenient pathway to facilitate spraying operations, (fig. 1). The experimental design followed a randomized block lay-out with 10 treatments, each replicated 6 times.

The treatments were as follows: Check, 10, 20, and 30 pounds to the acre of the sodium salt of 2,4-D, acid basis, applied 10, 20, and 30 days prior

FIG. 1.—Pathway prepared by cutting one row of cane between the experimental plots and the buffer strips to facilitate spraying operations.

to harvesting the cane. The larger concentrations used were intended to evoke a drastic change in the metabolism of the sugarcane plant. A common knapsack sprayer was used and the required quantity of the salt was dissolved in 1 gallon of water which was enough to spray thoroughly the cane in each plot. An extension was attached to the hose and the nozzle was tied to a bamboo pole 12 or 14 feet in length which could be raised well above the cane to permit the spray to fall on the cane foliage (fig. 2). The spraying operations were started about 6:00 A.M. to avoid violent drafts and thus minimize the error in spraying. Ten days after the last

treatment the cane was harvested from all plots and weighed in the field. Samples of 25 canes each were obtained from each plot at random and taken to the Station mill at Río Piedras. After grinding, the juice was

FIG. 2.—By using a bamboo pole 12 to 14 feet long, to which an extension to the hose of the sprayer was attached, it was possible easily to reach the foliage of the cane plants.

sampled and analyzed for Brix and polarization. From that data the purity and available 96° sugar percent cane were then calculated.

PRESENTATION OF DATA AND DISCUSSION

Table 1 gives a summary of the experimental data obtained at Humacao and Río Piedras, respectively. At Humacao the Brix values ranged from

18.9 to 20.6. The mean difference required for significance is 1.8. The mean polarization for juices ranged from 70.8 to 75.6, but the differences are not significant. The mean available 96° sugar percent cane was 12.2 for all combined treatments with deviations of only 0.5 percent above or below it. No significant differences were observed between the mean of

TABLE 1.—*Mean values for Brix, polarization, purity, available 96° sugar percent cane, and yield per acre of cane treated with 3 different concentrations of 2,4-D at 3 dates prior to harvest*

Days prior to harvest	2,4-D per acre	Brix	Polarization	Purity	Available 96° sugar percent cane	Cane per acre
			Results at Humacao[1]			
	Pounds	*Degrees*	*Degrees*	*Percent*		*Tons*
10	10	19.6	74.9	89.6	12.7	38.71
10	20	19.7	74.3	87.1	11.9	43.63
10	30	20.1	74.2	87.7	12.3	45.05
20	10	20.4	75.6	88.0	12.6	43.23
20	20	19.4	70.8	86.7	11.8	39.58
20	30	19.3	72.6	87.1	12.4	41.23
30	10	19.9	72.2	86.4	12.0	44.35
30	20	18.9	73.2	86.4	12.1	44.93
30	30	19.8	72.3	86.5	12.2	41.40
	0	20.6	75.6	86.9	12.5	43.06
			Results at Río Piedras[2]			
10	10	20.2	73.4	85.6	12.3	28.02
10	20	19.7	71.7	85.9	12.1	28.68
10	30	19.9	72.2	85.6	12.2	30.26
20	10	20.0	72.4	84.3	12.3	25.87
20	20	19.7	71.2	87.8	12.0	28.58
20	30	19.8	71.8	85.4	12.1	24.24
30	10	20.1	72.8	85.4	12.3	29.66
30	20	19.9	71.8	85.9	12.0	25.58
30	30	19.7	71.4	85.6	12.0	27.83
	0	20.1	73.3	86.4	12.4	27.70

[1] Minimum required for significance: Brix 1.8, polarization 5.8, purity 4.3, sugar percent cane 1, cane per acre 10.38.

[2] Minimum required for significance: Brix 0.7, polarization 3.4, purity 2.4, sugar percent cane 0.7, cane per acre 7.75.

treatments for available 96° sugar percent cane, purity, and tons of cane to the acre.

The results of the Río Piedras experiment follow about the same pattern as those from Humacao. The mean available 96° sugar percent cane for all combined treatments was 12.2, with maximum deviations of only 0.2

above or below it. In general, the differences between the means for Brix, polarization, purity, available 96° sugar percent cane, and tons of cane to the acre are not significant.

This preliminary attempt to offset the metabolism of the sugarcane plant at harvesttime was not successful. Perhaps the application of large doses of 2,4-D do not affect the metabolic activity of the cane plant as do smaller doses such as those used by Beauchamp (1). However, other factors may be of importance, such as the physical properties of the chemical used. In the literature available there is no mention to anything concerning the pH, wetability, rate of absorption by the plant, and other such properties of the chemical used, which in all probability have a tremendous importance in the final results obtained.

Additional work is under way to determine daily fluctuations, if any, in Brix, polarization, purity, and sucrose content of the cane after applications of 2,4-D. Smaller doses of 2,4-D will be applied and the changes in sucrose content will be traced daily for a certain period. Further work is contemplated with other growth regulators using a wide range of concentrations. The physiologic changes induced in the cane plant by preharvest foliage sprays with hormones should be investigated also. The careful study of the physiochemical properties of the materials used should help to clarify some of the fundamental concepts involved.

Summary

Data are presented here on the effect of applications to sugarcane of 10, 20, and 30 pounds to the acre of the sodium salt of 2,4-D, acid basis, at three intervals (10, 20 and 30 days) prior to harvest. Field experiments were conducted at Humacao and Río Piedras following a randomized block layout. Each treatment was replicated six times. The mean available 96° sugar percent cane was 12.2 at both locations with very small deviations above or below it. No significant differences were observed between the mean Brix, polarization, purity, available 96° sugar percent cane, and tons of cane to the acre at either location.

Resumen

Se presentan en este trabajo los datos obtenidos después de aplicar 10, 20, y 30 libras de la sal de sodio 2,4-D, base ácida, por acre, en tres períodos distintos (10, 20, y 30 días), antes de cosechar dos experimentos con caña de azúcar que se establecieron en Humacao y Río Piedras.

Estos experimentos de campo se establecieron siguiendo el diseño experimental de bloques al azar, con seis repeticiones por tratamiento.

La producción de sacarosa fué 12.2 por ciento, en promedio, con ligeras

desviaciones, tanto en el experimento en Humacao como en el de Río Piedras.

No hubo diferencias significativas entre los valores promedio de Brix, en la polarización, ni en la pureza, y tampoco en la sacarosa. No se registró diferencia alguna en el tonelaje de caña producido por acre en ambos experimentos.

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FACTORS AFFECTING THE SUCROSE CONTENT OF SUGARCANE: FERTILIZERS

G. Samuels, M. A. Lugo López and P. Landrau Jr.[1]

Introduction

In the fertilization of sugarcane, both tonnage and sucrose concentrations are important and must be given due consideration. The effect of increasing of cane tonnage by the use of fertilizers can be nullified if this increased yield is accompanied by a decrease in sucrose concentrations. On the other hand, no increase in yields of cane per acre would be entirely acceptable if the fertilizer decreased sucrose concentrations significantly.

As a quantitative illustration of the intimate relationship between cane tonnage and sucrose concentrations, the following example may prove of value.

A field produces 40 tons of millable cane per acre with a mean sucrose concentration of 12 percent. This gives 96 hundredweights of sugar. If by the use of fertilizers we were to increase the sucrose content of the cane but 1 percent, from 12 to 13, the yield of sugar would be 104 hundredweights per acre. To obtain the same quantity of sugar per acre from the 12-percent cane, it would be necessary to obtain an increase of 3.3 tons. It is also to be remembered that increased sucrose content means more sugar per acre without increased cane tonnage which involves higher labor costs in harvesting. That is, by harvesting 40 tons of a 13-percent cane a grower obtains the same amount of sugar per acre as does the grower who harvests 43.3 tons of a 12-percent cane, with the added profit that the farmer does not have to pay the labor costs involved for harvesting the extra 3.3 tons of cane. This example emphasizes that, for proper evaluation of sugarcane fertilizers, consideration should be given not only to influence on cane tonnage but also to influence on sucrose concentration.

The literature on sugarcane fertilizers abounds in data concerning fertilizers and cane tonnage. The data related to fertilizers and sucrose concentrations are not so plentiful and are rather conflicting (5).[2] It is the purpose of this paper to present and interpret the data on the influence of fertilizer on sucrose concentrations for Puerto Rico, as determined by over 15 years of fertilizer research conducted by the Agricultural Experiment Station of the University of Puerto Rico.

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[2] Numerals in parentheses refer to Literature Cited, p. 202.

Effects of Major-Element Fertilizers

NITROGEN

In Puerto Rico, nitrogen is responsible for more increases in cane tonnage than any other fertilizer element. The data from 152 field experiments of the Agronomy Department covering the leading sugarcane varieties and producing areas were utilized in determining the influence of nitrogen on sucrose percent cane. The results are presented in figure 1, expressed in

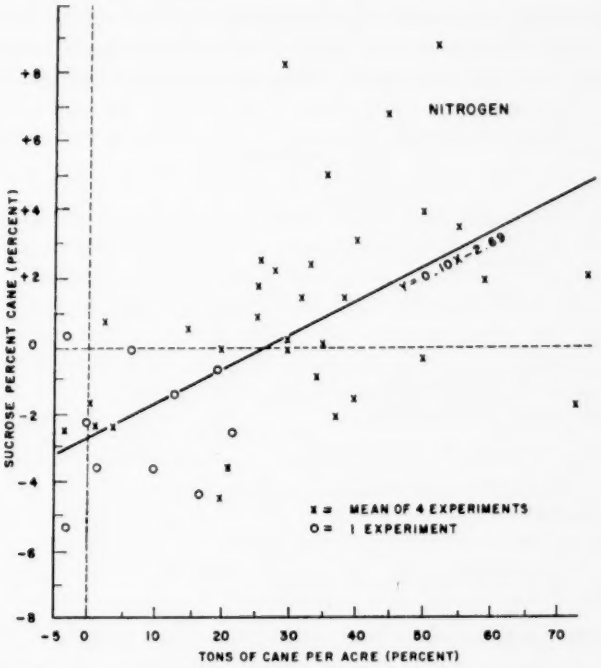

Fig. 1.—Influence of nitrogen fertilizer on the percentage increase or decrease in tons of cane per acre and in sucrose percent cane.

percentage increase in yield and in sucrose percent cane. This percentage increase represents the increase in either tons of cane or sucrose of treatments with nitrogen fertilizer when compared to the no-nitrogen treatment. The graph shows a definite linear relationship between percentage increase in tons of cane and percentage increase in sucrose percent cane. The regression equation obtained was $Y = 0.10x - 2.69$ where Y is the percentage increase in sucrose percent cane and x is the percentage increase in tons of cane per acre. The regression of percentage increase in sucrose percent

cane on percentage increase in tons of cane per acre was very highly significant at the 1-percent level.

It is often stated in discussing sugarcane fertilization that the use of nitrogen in large quantities lowers the sucrose content of the cane. The data presented in figure 1 do not support this belief. The findings here indicate that an increase in yield of cane per acre obtained by the use of more nitrogen is accompanied by an increase in sucrose percent cane. However, as revealed by the equation $Y = 0.10x - 2.69$, an increase in sucrose percent cane is only realized after the percentage increase in tons of cane reaches 27. Thus, small increases in cane tonnage are not accompanied by appreciable increases in sucrose content, but by decreases. The use of nitrogen on cane which has no need for it, or of large quantities of nitrogen for

TABLE 1.—*Influence of different nitrogen sources on sucrose percent cane for P.O.J. 2878 at Rio Piedras*

Treatment				Sucrose percent cane[1]
Nitrogen carrier	Fertilizer per acre			
	N	P_2O_5	K_2O	
	Pounds	*Pounds*	*Pounds*	*Percent*
None	0	50	50	12.18
Ammonium sulfate	206	50	50	12.20
Ammonium nitrate, 1 application	206	50	50	12.18
Ammonium nitrate, 2 applications	206	50	50	12.07
Uramon	206	50	50	12.33
Significant difference needed between treatments at the:				
5-percent level				0.57
1-percent level				.75

[1] Average of a plant cane and two ratoons.

cane which needs but moderate fertilization, will produce little increase in tons of cane, and the sucrose content will either not be affected or slightly decreased. When nitrogen was used on cane which responded by an increased yield of over 27 percent, there were increases in the sucrose content of the cane.

The source of nitrogen used for sugarcane had no influence on the sucrose content of the cane in experiments conducted at Río Piedras. In table 1, the data show no significant difference regardless of nitrogen sources or the manner of application. Data given in a previous publication (8) also revealed no significant influence on yield of cane attributable to nitrogen source. Similar work in Hawaii (1) failed to reveal any difference in the sucrose yields of canes fertilized with various nitrogen carriers, namely,

nitrate of soda, ammonium sulfate, potassium nitrate, calcium nitrate, urea, Calurea, Uramon, and ammonium nitrate.

Clements (2) states that the addition of large quantities of nitrogen means an accompanying need of the sugarcane plant for more carbohydrates, and as a result, comparatively small quantities are stored by the plant. By applying a heavy dose of nitrogen, Clements believes the storage capacity of the cane is increased, but less is left to be stored. However, for the conditions of the experiments reported in this paper, increasing the cane tonnage was accompanied by an increase in sucrose. The maximum nitrogen used was 250 pounds per acre. It is, of course, plausible to expect a decrease in both tonnage and sucrose with too heavy applications of nitrogen. For Puerto Rico, it appears that the use of up to 250 pounds of nitrogen per acre for cane is not harmful either to sucrose percent cane or tonnage.

PHOSPHORUS

The results of 144 field experiments showed no significant response in the sucrose content of cane from phosphorus fertilizers. The data shown in figure 2 reveal no definite trend in sucrose response to the use of phosphorus. In general, there is a very little difference in yield of cane attributable to phosphorus, the response on the average being less than a 10-percent increase. The majority of the increases in sucrose percent cane lie within a -6 to $+3$ range. The graph indicates that no decreases in tons of cane were accompanied by decreases in sucrose content. Where large increases in tons of cane were encountered (over 10 percent), the response in sucrose percent cane was sometimes negative and sometimes positive.

Martin (6) and Saito and Kenjo (7) reported a reduction in the sucrose content of cane grown in nutrient solutions. However, these reductions were not observed in field work (3, 9). The phosphorus needed for sugarcane to perform its normal physiological role in sucrose formation and accumulation seemed to be adequately supplied by the sugarcane soils of Puerto Rico.

POTASSIUM

The data from 144 field experiments revealed no significant difference in sucrose concentration attributable to potassium fertilizers. In general, the response in yield from potash applications was low. The majority of the increases in tons of cane per acre were less than 10 percent, and the maximum was 18. (See figure 3). The increases in sucrose concentration were generally accompanied by yield increases. These increases in sucrose were not consistent, and figure 3 shows increases in sucrose concentration varying from -8 to $+8$ percent all within a range of a 2- to 10-percent increase in tons of cane.

Although, the majority of the sucrose increases were positive (72 percent), there was no significant relationship between the application of potash and sucrose concentrations. The reason may be that only small yield responses are obtained from potash fertilizers in Puerto Rico. The evidence in the literature on the influence of potash on sucrose content is controversial. A careful examination reveals that potassium is essential for high sucrose values, and that its complete omission leads to low sucrose con-

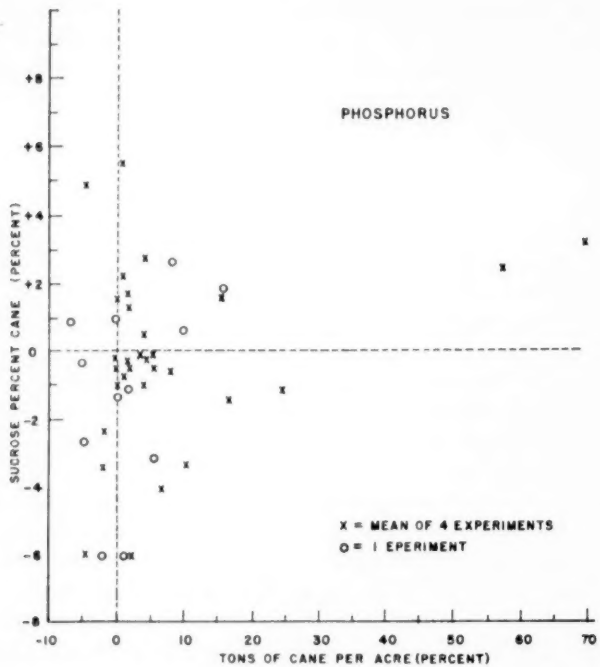

FIG. 2.—Influence of phosphorus fertilizer on the percentage increase or decrease in tons of cane per acre and in sucrose percent cane.

centrations. However, the soils of Puerto Rico seem to contain sufficient potash to ensure good sucrose concentrations. The application of potash then, does not necessarily produce an increase in the sucrose content of the cane. Innes (4) in Jamaica obtained significant increases in the sucrose percent cane only when yield responses were 20 percent or greater. It must be remembered that the highest yield increase found in figure 3 was 18 percent. If further responses in yield are possible, it may be that increases in sucrose concentrations will follow.

Effects of Minor-Element Fertilizers

The use of minor-element fertilizers on sugarcane has produced no general significant increases in the sucrose content of cane in Puerto Rico. This is also true for cane tonnage. The response of sugarcane as increases in tons of cane and sucrose percent cane from the use of minor element fertilizers is shown in figure 4. The tonnage increase is almost always lower than 7 percent. The sucrose results are sometimes negative and sometimes positive.

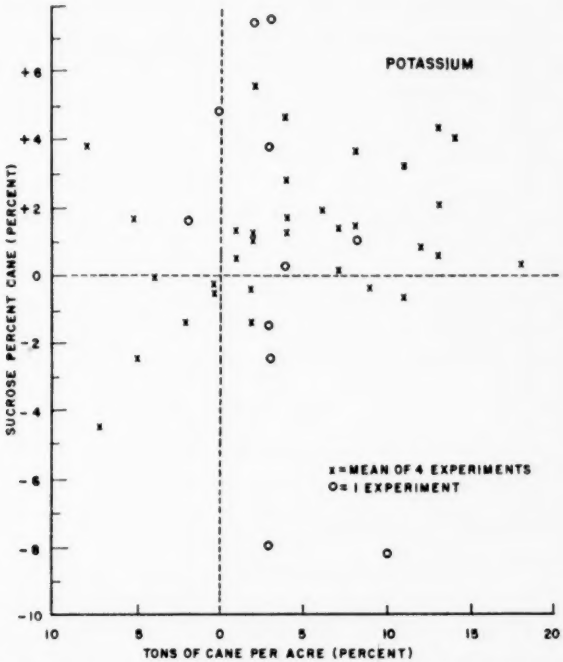

Fig. 3.—Influence of potassium fertilizer on the percentage increase or decrease in tons of cane per acre and in sucrose percent cane.

Magnesium produced 4 negative responses and also 3 positive responses in sucrose percent cane. Copper gave increases in sucrose for all 4 experiments in which it was used; the increases ranged from 1.3 to 7.2 percent. However, the yield decreases or increases in cane ranged from −14.4 to +10.8 percent.

Zinc and manganese produced both negative and positive responses in sucrose concentration. Boron showed 4 positive responses and 1 negative response in the 5 experiments in which it was used. The application of

sodium did not produce any definite positive response in sucrose content. Iron and sulfur produced increases in sucrose content. Results with calcium were both positive and negative from the standpoint of increases in sucrose. The soils where the lime was used, however, all had a pH above 6.2.

There is no evidence in the literature of any appreciable increases in sucrose content of sugarcane with the use of minor-element fertilizers. Nutrient-culture work, in which a minor element was entirely omitted from the medium, provided some evidence of the need of certain minor elements for normal sucrose production. Most soils, however, have sufficient supplies

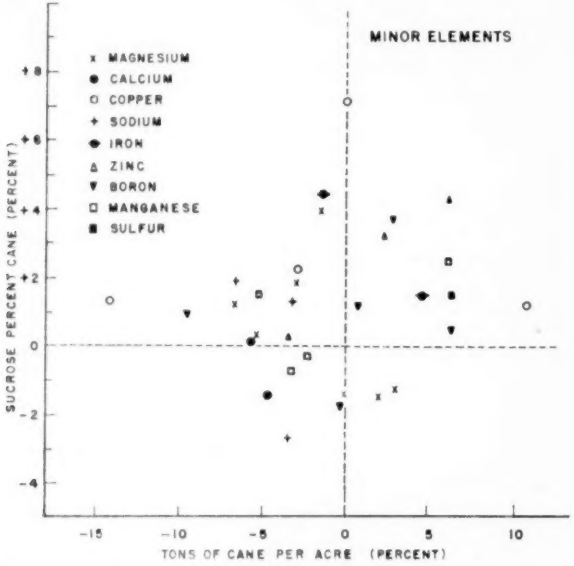

FIG. 1.—Influence of certain minor-element fertilizers on the percentage increase or decrease in tons of cane per acre and in sucrose percent cane.

of the needed minor elements, and no appreciable responses are obtained in yield or sucrose content.

SUMMARY

The results of over 150 field experiments with sugarcane conducted by the Agricultural Experiment Station of the University of Puerto Rico covering a wide range of varieties and soils of Puerto Rico revealed the following:

1. Nitrogen produced an increase in sucrose content with increased cane yields. When the percentage increase in cane tonnage is plotted against

the percentage increase in sucrose percent cane, a highly significant regression is obtained. The equation obtained reveals that a significant increase in sucrose concentration occurs only after increases in yields are over 27 percent.

2. Different nitrogen sources, namely, ammonium nitrate, ammonium sulfate, and Uramon, produced no significant differences in influence on sucrose concentrations.

3. The application of phosphorus had no significant effect on the sucrose content of sugarcane. Cane tonnage responses were also slight.

4. The use of potassium fertilizers did not significantly influence the sucrose content of sugarcane. Where there was an increase in yield, there was generally an increase in sucrose content. Percentage increases in yield of cane, however, were very low, the majority being less than 10 percent. The soils seem to contain sufficient potassium for good sucrose concentrations, and the use of potash as fertilizer does not usually produce any significant increases in sucrose.

5. The minor-element fertilizers produced no significant increases in sucrose content. The use of copper, magnesium, zinc, boron, manganese, calcium, sodium, iron, and sulfur produced no appreciable increases in yield. The majority of percentage yield increases were less than 7, while percentage decreases or increases in sucrose content varied from -3 to $+7$.

Resumen

Los resultados de más de 150 experimentos de campo con distintas variedades de caña azúcar, llevados a cabo por la Estación Experimental Agrícola de la Universidad, en distintos suelos de Puerto Rico señalan lo siguiente:

1. La aplicación de nitrógeno produjo un aumento en el contenido de sacarosa y en los rendimientos. Cuando se calculó el porcentaje de aumento en el tonelaje producido comparándolo con el porcentaje de aumento del por ciento de sacarosa se obtuvo una regresión altamente significativa. En este caso, la ecuación revela que el aumento significativo en la concentración de sacarosa se obtuvo sólo cuando los aumentos en los rendimientos fueron sobre el 27 por ciento.

2. Las diferentes fuentes de nitrógeno, a saber, nitrato de amonio, sulfato de amonio, y Uramón no tuvieron influencia significativa sobre las concentraciones de sacarosa.

3. La aplicación de fósforo no ejerció efecto significativo alguno sobre el contenido de sacarosa en la caña, como también fué insignificante su influencia sobre los rendimientos.

4. La aplicación de potasio no tuvo efecto significativo alguno sobre el

contenido de sacarosa en la caña. Cuando se registró un aumento de la sacarosa, generalmente hubo un aumento en el contenido de sacarosa. Los porcentajes de aumento en los rendimientos fueron, sin embargo, muy bajos, en su mayoría menos del 10 por ciento.

Tal parece que los suelos contienen suficiente potasio para proveer una buena concentración de sacarosa, por lo que la presencia de este elemento en los abonos no aumenta de por sí el contenido de sacarosa en la caña.

5. La aplicación de los elementos menores conjuntamente con los abonos no surte efecto significativo alguno en el contenido de sacarosa. Los siguientes elementos menores, magnesio, zinc, boro, manganeso, calcio, sodio, hierro y azufre no produjeron aumentos apreciables en los rendimientos. El porcentaje de aumento en los rendimientos fué en su mayoría menor del 7, mientras que el de los cambios en el contenido de sacarosa varió de -3 a $+7$.

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THE RESPONSE OF SUGARCANE TO FERTILIZERS

I. THE ARECIBO CYCLE, 1944–1950

George Samuels and Pablo Landrau, Jr.[1]

Introduction

PURPOSE

The annual import of fertilizers and fertilizer material into Puerto Rico amounts to over 100,000 tons[2], of which over 70 percent[3] is used for the fertilizing of sugarcane. The fertilizer imports rose from 43,260 tons in 1922–23 to 191,714 in 1949–50. Over four times as much fertilizer material is being applied to sugarcane fields today as 30 years ago. This increased use of fertilizer for sugarcane clearly indicates the importance placed by the growers on fertilizing this crop.

The increased use of sugarcane fertilizers has not been accompanied by as great an increase in knowledge of how to use it. Although advances have been made in our knowledge about fertilizing sugarcane, they have been in rather general terms. Information is lacking on the fertilizer elements and the quantities needed of each for specific sugarcane varieties and soils. It was the object of the Agronomy Department of the Agricultural Experiment Station of the University of Puerto Rico to gain more precise information on the fertilizer needs of sugarcane.

The experiments undertaken here were designed to test various levels of nitrogen, phosphorus, and potassium on leading cane varieties. The sites selected were on the important sugarcane soils of the Island. The experiments were to be continued not merely for a plant-cane and a ratoon crop, as in previous work, but for a long period of time covering several cycles of plant cane and many ratoons, the ultimate purpose being to obtain a complete picture of the influence of the fertilizers on sugarcane, the soil, and the variety over a long period under the controlled conditions of a field experiment.

[1] Plant Physiologist and Assistant Agronomist, respectively, of the Agricultural Experiment Station of the University of Puerto Rico, Río Piedras, P. R. The authors wish to express their appreciation to the following for their fine cooperation in the field and the laboratory: O. Reyes, R. Irizarry, S. Gaztambide, F. Aróstebui, P. Richardson, F. Rochet, C. Rivera, J. A. Bonnet, A. Riera, F. J. Ascorbe, G. N. Calcaño, and Hipólito Monserrate. They also wish to thank the Land Authority of Puerto Rico for its fine cooperation, and B. G. Capó, Assistant Director for Research of the Agricultural Experiment Station of the University of Puerto Rico, for his guiding effort in this work.

[2] Mean of period 1921–1950 compiled from data taken from (4).[4]

[3] Mean of period 1942–1949 compiled from data taken from (7).

[4] Numerals in parentheses refer to Literature Cited, pp. 228–29.

This paper reports the first cycle of a plant cane and four ratoons of the Arecibo experiment on Coloso silty clay.

PROCEDURES

A sugarcane fertilizer-variety experiment was begun on September 18, 1944, on the San Francisco farm of the Land Authority of Puerto Rico at Arecibo. The experiment consisted of growing four sugarcane varieties (P.O.J. 2878, P.R. 903, M. 275, and M. 317) at seven different fertilizer levels of nitrogen, phosphorus, and potassium, on a Coloso silty clay. The

TABLE 1.—*Harvesting dates for 4 sugarcane varieties planted September 18 to 20, 1944, and age of the cane when harvested*

Crop	Harvesting date	Age of cane
		Months
Plant cane	February 25–March 4, 1946	17
First ratoon	April 6–8, 1947	13
Second ratoon	April 6–8, 1948	12
Third ratoon	April 18–23, 1949	13
Fourth ratoon	May 10–13, 1950	12

TABLE 2.—*Fertilizer treatments used (rates of application per acre) for 4 sugarcane varieties planted September 18 to 20, 1944*

Treatment No.	Fertilizer applied per acre		
	N	P_2O_5	K_2O
	Pounds	*Pounds*	*Pounds*
1	0	300	300
2	125	300	300
3	250	0	300
4	250	150	300
5	250	300	0
6	250	300	150
7	250	300	300

harvesting dates for the plant-cane and ratoon crops and the age of the cane at harvest are given in table 1.

The design of the experiment was a split-plot one in which varieties were considered as the whole-plot effect and the various levels of the fertilizer were regarded as the sub-or split-plot effect. The plots were 30 feet long, 18 feet wide, or 540 square feet. In other words, each plot of the four varieties tested was subdivided into 7 parts on which various levels of fertilizer were used as shown in table 2. There were four cane furrows to each plot. The actual field design of the experiment is shown in figure 1.

241 C-5	242 B-7	243 D-4	244 A-1
229 C-6	230 B-3	231 D-1	232 A-4
217 C-4	218 B-2	219 D-5	220 A-7
205 C-7	206 B-1	207 D-7	208 A-3
193 C-3	194 B-5	195 D-6	196 A-2
181 C-1	182 B-4	183 D-2	184 A-6
169 C-2	170 B-6	171 D-3	172 A-5

Block 7

245 D-6	246 C-3	247 A-7	248 B-5
233 D-5	234 C-4	235 A-6	236 B-2
221 D-4	222 C-6	223 A-2	224 B-3
209 D-2	210 C-1	211 A-4	212 B-1
197 D-7	198 C-5	199 A-1	200 B-4
185 D-3	186 C-7	187 A-5	188 B-6
173 D-1	174 C-2	175 A-3	176 B-7

Block 8

249 D-3	250 A-1	251 C-2	252 B-5
237 D-1	238 A-4	239 C-3	240 B-2
225 D-7	226 A-5	227 C-4	228 B-1
213 D-5	214 A-7	215 C-5	216 B-6
201 D-4	202 A-2	203 C-6	204 B-7
189 D-2	190 A-6	191 C-1	192 B-3
177 D-6	178 A-3	179 C-7	180 B-4

Block 9

157 D-3	158 C-4	159 A-7	160 B-6
145 D-7	146 C-6	147 A-1	148 B-4
133 D-6	134 C-3	135 A-4	136 B-7
121 D-2	122 C-7	123 A-5	124 B-1
109 D-5	110 C-2	111 A-6	112 B-5
97 D-1	98 C-5	99 A-3	100 B-2
85 D-4	86 C-1	87 A-2	88 B-3

Block 4

161 C-5	162 A-3	163 B-2	164 D-6
149 C-4	150 A-6	151 B-3	152 D-2
137 C-1	138 A-4	139 B-7	140 D-3
125 C-2	126 A-7	127 B-5	128 D-4
113 C-3	114 A-2	115 B-1	116 D-7
101 C-6	102 A-1	103 B-4	104 D-5
89 C-7	90 A-5	91 B-6	92 D-1

Block 5

165 C-1	166 D-5	167 B-2	168 A-3
153 C-4	154 D-6	155 B-5	156 A-7
141 C-2	142 D-1	143 B-6	144 A-4
129 C-6	130 D-7	131 B-3	132 A-1
117 C-5	118 D-3	119 B-4	120 A-2
105 C-3	106 D-2	107 B-7	108 A-6
93 C-7	94 D-4	95 B-1	96 A-5

Block 6

73 C-6	74 A-3	75 B-7	76 D-4
61 C-7	62 A-1	63 B-2	64 D-1
49 C-2	50 A-6	51 B-1	52 D-3
37 C-1	38 A-5	39 B-4	40 D-2
25 C-4	26 A-2	27 B-6	28 D-7
13 C-3	14 A-4	15 B-5	16 D-6
1 C-5	2 A-7	3 B-3	4 D-5

Block 1

77 B-1	78 C-2	79 D-4	80 A-5
65 B-5	66 C-6	67 D-7	68 A-3
53 B-7	54 C-4	55 D-2	56 A-1
41 B-3	42 C-7	43 D-5	44 A-4
29 B-2	30 C-5	31 D-6	32 A-2
17 B-4	18 C-3	19 D-1	20 A-6
5 B-6	6 C-1	7 D-3	8 A-7

Block 2

81 D-3	82 B-6	83 A-7	84 C-2
69 D-4	70 B-2	71 A-1	72 C-3
57 D-6	58 B-5	59 A-4	60 C-7
45 D-7	46 B-3	47 A-2	48 C-1
33 D-1	34 B-7	35 A-5	36 C-6
21 D-5	22 B-4	23 A-3	24 C-4
9 D-2	10 B-1	11 A-6	12 C-5

Block 3

FIG. 1.—Field design of the experiment.

The analysis of variance was calculated as described by Cochran and Cox (3). The crop was planted September 18–20, 1944, 32 seed pieces to the furrow or 10,325 to the acre.

The fertilizer for each treatment was compounded from ammonium sulfate (20-percent N), superphosphate (20-percent P_2O_5), and potassium chloride (60-percent K_2O). The mixed fertilizer for each plot was applied by hand in the row under the seed piece before planting and at the base of the stools for the ratoons. All fertilizer was applied at once for each crop, and as soon after cutting the ratoon as conditions would permit.

The cane was cut as in commercial practice. The cane from each plot was weighed separately in the field using a portable crane and weighing baskets. Ten whole stalks of cane minus the tops were taken at random from each plot at the time of cutting. These canes were tagged as to origin and brought to the hydraulic mill at the Agricultural Experiment Station at Río Piedras for the determination of the sucrose content. All canes sampled were milled not later than 24 hours after cutting.

Beginning with the second ratoon, leaf samples to be used for foliar diagnosis were taken from the cane in each plot at a cane age of 3 months. The leaves selected were the four nearest the last emerged unopened leaf. They were obtained from 12 sugarcane shoots, 3 shoots being selected at random from each row of the four rows of the cane plot. Thus, 48 elongating leaf blades were cut at the collar joint of cane from each plot.

These leaf samples were then taken to the laboratory where they were cut with a knife-board paper trimmer, so that a 1-inch section was obtained from the basal, middle, and terminal portion of each. This gave 144 approximately 1-inch-square leaf sections per plot for analysis. The cut samples were oven-dried at 70°C, ground to 60-mesh, digested with acid, and analyzed for nitrogen, phosphorus, and potassium by the Soils Department (1).

The Area

TOPOGRAPHY

The Arecibo area is located on the northwestern coast of Puerto Rico. The experimental area is located at the mouth of a large, level valley through which the Río Grande de Arecibo flows. The valley, which is about 15 feet above sea level, is surrounded by high limestone hills. The site of the experiment is 8 kilometer from the city of Arecibo on the road to Utuado. The level land of the valley is devoted almost 100 percent to the growing of sugarcane. The cane land is mainly owned and managed by the Land Authority of Puerto Rico. The sugar centrals Cambalache and Los Caños are located in this fertile valley.

RAINFALL

The mean annual rainfall of this area, as recorded for a 26-year period, was 60.56 inches (5). The rainfall for the period 1944 to 1950, in which the experiment was conducted, is given in table 3. The mean for this period

was 53.68 inches annually, 6.88 inches below the mean of the 26-year period for which rainfall records were available. No severe deficiencies nor excesses of rainfall which might be considered as a limiting factor in the experiment were encountered in the 1944 to 1950 period. The monthly rainfall records show a rather even distribution throughout the year.

Sugarcane Response to Different Fertilizer Levels

HUNDREDWEIGHTS OF 96° AVAILABLE SUGAR PER ACRE

Nitrogen

The use of nitrogen produced yield increases for every crop (see table 4). The use of 125 pounds of nitrogen per acre gave a highly significant

TABLE 3.—*Record of rainfall for Arecibo during period 1944-1950*[1]

Year	Inches of rain per month												Total for year
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1944	2.70	1.02	1.09	1.45	8.85	6.82	4.28	4.28	5.31	10.16	4.79	5.32	56.70
1945	1.68	3.15	1.65	2.99	11.09	3.49	4.06	4.42	5.56	6.96	6.14	.77	51.96
1946	4.26	1.02	3.32	5.76	4.45	6.40	1.38	3.63	3.07	4.94	3.23	9.33	50.79
1947	3.28	3.35	.48	2.30	6.41	3.24	0	6.26	3.95	8.29	2.52	7.58	46.64
1948	3.48	4.15	1.17	3.09	10.28	2.54	2.45	5.06	2.70	3.58	5.74	2.72	46.96
1949	5.63	2.40	7.65	0	5.09	2.37	5.07	4.23	6.44	6.57	6.58	4.35	56.38
1950	9.00	13.49	2.79	5.36	3.31	.56	3.29	6.46	3.13	6.36	9.60	2.96	66.31
Mean	4.29	4.08	2.59	2.99	7.07	3.63	2.93	4.91	4.31	6.69	5.51	4.72	53.68
Mean of 26 years[2]	5.44	4.07	4.05	4.50	5.50	3.32	5.01	4.52	4.83	4.73	8.52	6.07	60.56

[1] Prepared from the Climatological Data, West Indies and Caribbean, U. S. Department of Commerce, Weather Bureau, 1944 to 1950.

[2] Data derived from table 3, page 48 (5).

increase in sugar per acre; this amounted to 69 hundredweights of sugar for the plant cane and averaged 34 hundredweights for the ratoons.

The use of an additional 125 pounds of nitrogen per acre did not give as great an increase in yield as did the first 125 pounds. For the plant cane, 250 pounds of nitrogen per acre gave 29 hundredweights more sugar per acre than 125 pounds; for the ratoons the average increase was only 6 hundredweights. In fact, the response to 250 pounds of nitrogen over 125 pounds decreased with the number of ratoons. From plant cane to fourth ratoon, the increase or decrease in hundredweights of sugar for 250 pounds of nitrogen over 125 pounds (treatment 7 minus treatment 2) was 29, 15, 6, 2, and −1. It seems evident from this that in this experiment, higher nitrogen applications were not as beneficial for older ratoons as for plant cane or new ratoons.

Phosphorus

There was no general significant response in yields of sugar per acre from the use of phosphorus fertilizer (see table 4). There was a difference of only 3 hundredweights of sugar per acre between no phosphorus and 300 pounds of P_2O_5 per acre (treatment 7 minus treatment 3) for the mean of the five crops. This difference was not significant statistically. This, of course, does not mean that phosphorus was not needed by the sugarcane. Although no responses occurred in the plant cane and first ratoon, there were responses to 150 pounds of P_2O_5 per acre in the second and fourth ratoons. After 3 years the plots that received 150 pounds of P_2O_5 per acre

TABLE 4.—*Yields of the mean of 4 varieties of sugarcane in hundredweights of available 96° sugar when grown at different fertilizer levels*

Treatment No.	Treatments in pounds per acre			Mean yields in hundredweights of available 96° sugar per acre					Mean of 5 crops
	N	P_2O_5	K_2O	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
1	0	300	300	124	84	83	83	102	95
2	125	300	300	193	122	107	118	139	136
3	250	0	300	226	133	109	116	131	143
4	250	150	300	224	132	115	118	137	145
5	250	300	0	214	126	103	106	117	133
6	250	300	150	216	131	110	113	128	140
7	250	300	300	222	137	113	120	138	146
Mean for all treatments				203	124	106	111	127	134
Least significant difference needed between treatments of same crop:									
5-percent level				10	6	5	5	5	4
1-percent level				14	8	6	6	7	5

yielded 6 hundredweights of sugar more than those receiving no phosphorus. This difference was significant at the 5-percent level.

The minimum P_2O_5 used was 150 pounds per acre. This was probably above a satisfactory minimum level. Consistent high yields have been obtained in long-range fertilizer trials (6) with the use of 20 pounds of P_2O_5 per acre yearly, as compared with 80 pounds. The use of from 40 to 50 pounds of P_2O_5 per acre per year would seem to be well above any deficiency level for sugarcane, except perhaps for soils with extreme phosphorus deficiency. Rates higher than 40 to 50 pounds per acre annually will not produce higher yields and only add to the cost of fertilizing the cane.

Potassium

The Coloso silt loam on which this experiment was performed shows need for potassium. The needs and responses from potassium fertilizers were not as great as for nitrogen, but significant increases in yields were realized when potash was used. The responses obtained were greater as the number of ratoons increased. No significant response was obtained in the plant cane (see table 4). The first ratoon did respond significantly to potassium up to levels of 300 pounds of K_2O per acre. Responses from potash were obtained for the second, third, and fourth ratoons, the response being greater for the fourth ratoon than for the first.

TABLE 5.—*Sucrose percent cane of the mean of 4 varieties of sugarcane when grown at different fertilizer levels*

Treatment No.	Treatments in pounds per acre of—			Mean yield in sucrose percent cane					Mean of 5 crops
	N	P_2O_5	K_2O	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
1	0	300	300	12.41	11.38	10.95	11.77	12.86	11.88
2	125	300	300	12.91	11.56	11.04	11.79	12.87	12.04
3	250	0	300	12.68	11.54	10.62	11.61	12.60	11.81
4	250	150	300	12.58	11.37	10.91	11.57	12.54	11.80
5	250	300	0	12.57	11.08	10.40	11.05	12.09	11.44
6	250	300	150	12.40	11.22	10.61	11.28	12.26	11.56
7	250	300	300	12.65	11.60	10.78	11.67	12.59	11.86
Mean for all treatments				12.60	11.39	10.76	11.53	12.53	11.77
Least significant difference needed between treatments of same crop:									
5-percent level				0.35	0.28	0.45	0.28	0.32	0.35
1-percent level				.47	.37	.60	.37	.42	.46

The mean of the five crops showed an increase of 7 hundredweights of sugar per acre for 150 pounds of K_2O; when 300 pounds of K_2O per acre were used the increase was 13 hundredweights. From the data in table 4, it appears that, in this experiment, higher potassium rates were more beneficial to the ratoons than to the plant canes, the response being greater as the number of ratoons increased.

SUCROSE-PERCENT-CANE CONTENT

Nitrogen

Nitrogen had no significant influence on the sucrose content of the cane (see table 5). The use up to 250 pounds of nitrogen per acre neither increased

nor decreased sucrose concentrations significantly; this was true of the plant cane and four ratoons.

Phosphorus

The use of phosphate fertilizers did not change sucrose concentrations appreciably (table 5). There was no response by any of the five crops grown.

Potassium

The omission of potash lowered the sucrose content of the sugarcane. There was no effect on the plant cane, but in the first ratoon a significant increase in sucrose concentration occurred when 300 pounds of K_2O per acre were used. For all the other ratoons except the second, there was a significant increase in sucrose from the use of 300 pounds of K_2O per acre

TABLE 6.—*Yields of the mean of 4 varieties of sugarcane in tons of cane per acre when grown at different fertilizer levels*

Treatment No.	Treatments in pounds per acre of—			Mean yield in tons of cane per acre					Mean of 5 crops
	N	P_2O_5	K_2O	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
1	0	300	300	50.0	36.9	37.9	35.3	39.7	40.0
2	125	300	300	74.7	52.7	48.5	50.0	54.0	56.0
3	250	0	300	89.1	57.6	51.3	50.0	52.0	60.0
4	250	150	300	89.0	58.0	52.7	51.0	54.6	61.1
5	250	300	0	85.1	56.9	49.5	48.0	48.4	57.6
6	250	300	150	87.1	58.4	51.8	50.1	52.2	59.9
7	250	300	300	87.7	59.1	52.4	51.4	54.8	61.1
Mean for all treatments				80.4	54.2	49.2	48.0	50.8	56.5

over no potash. The use of 150 pounds of K_2O per acre produced no significant increase as compared with the no-potash treatment.

TONS OF CANE PER ACRE

As shown in table 6, the responses in tons of cane per acre were similar to those for hundredweights of sugar per acre shown in table 4. The greatest response was for nitrogen, then potassium, and last phosphorus.

VARIETY RESPONSES IN GENERAL

HUNDREDWEIGHTS OF 96° AVAILABLE SUGAR PER ACRE

The leading variety was P.R. 903, which gave significantly greater yields of sugar per acre than any of the other three varieties (see table 7). P.O.J. 2878 and M. 317 were second in yields, there being no significant yield

difference between them. Variety M. 275 gave the lowest yields of sugar per acre. The increase in yields of sugar per acre for the mean of five crops from using P.R. 903 instead of M. 275 was 21 hundredweights, or 17 percent (see table 7).

TABLE 7.—*Mean yields of 4 varieties of sugarcane in hundredweights of available 96° sugar per acre*

Varieties	Mean yields in hundredweights of available 96° sugar per acre					Mean of 5 crops
	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
P.O.J. 2878	181	124	113	118	123	132
P.R. 903	232	136	108	117	137	146
M. 317	207	122	103	111	126	134
M. 275	191	113	99	97	122	125
Mean of all varieties	203	124	106	111	127	134
Least significant difference needed between varieties of same crop:						
5-percent level	12	8	6	8	7	6
1-percent level	17	11	8	11	9	9

TABLE 8.—*Mean sucrose percent cane for 4 varieties of sugarcane*

Variety	Mean yield in sucrose percent cane					Mean of 5 crops
	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
P.O.J. 2878	12.47	11.44	10.98	11.50	12.44	11.77
P.R. 903	12.70	11.54	10.78	11.77	12.73	11.91
M. 275	12.45	11.20	10.67	11.34	12.47	11.63
M. 317	12.78	11.39	10.60	11.53	12.53	11.77
Least significant difference needed between treatments of same crop:						
5-percent level	0.42	0.41	0.26	0.40	0.22	0.23
1-percent level	.57	.56	.35	.56	.31	.31

SUCROSE-PERCENT-CANE CONTENT

There was no appreciable difference in the sucrose content of the four varieties. For the plant cane and first ratoon there were no significant differences (see table 8). In the second ratoon P.O.J. 2878 contained the most sucrose, but P.R. 903 was highest in the third and fourth ratoons. M. 275 was the lowest in sucrose except in the fourth ratoon. For the mean of the five crops, P.R. 903 was significantly higher in sucrose than M. 275 only.

TONS OF CANE PER ACRE

Variety P.R. 903 gave the highest yield in tons of cane per acre with a mean of 60.8 tons. This was followed by M. 317, P.O.J. 2878, and M. 275, in order, the yields all being very similar and below that of P.R. 903 (see table 9). The plant cane P.R. 903 yielded 91.3 tons per acre; this was over 18 tons more cane per acre than P.O.J. 2878. For the mean of the five crops, P.R. 903 yielded 8.4 tons of cane more than M. 317, which had the lowest mean varietal yield.

Variety Responses at Different Fertilizer Levels

The response to a given fertilizer element at a given level need not necessarily be the same for different sugarcane varieties. Because of certain differences in vegetative structure one variety may be able to make more use of a given fertilizer element than another. One of the special objectives

TABLE 9.—*Mean yields of 4 varieties of sugarcane in tons of cane per acre*

Varieties	Mean yields in tons of cane per acre					Mean of 5 crops
	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
P.O.J. 2878	72.6	54.2	51.5	51.3	49.4	55.8
P.R. 903	91.3	58.9	50.1	49.7	53.8	60.8
M. 275	83.1	54.5	48.3	49.0	50.5	57.1
M. 317	74.7	49.6	46.7	42.1	48.7	52.4
Mean of all varieties	80.4	54.3	49.2	48.0	50.6	56.5

of this experiment was to note the behavior of different varieties at different fertilizer levels. If varieties do tend to behave differently at various fertility levels, the regular variety trial at one fertility level would seem to be invalid, or at least incomplete. However, if varieties compared in a field trial maintain their same rank at different fertilizer levels, the use of only one fertility level for varietal trials is valid. The results here presented show that varieties do tend to keep their rank when compared at different fertility levels, and that large, complex variety experiments at different fertility levels do not seem to be needed for general work with sugarcane.

HUNDREDWEIGHTS OF AVAILABLE 96° SUGAR PER ACRE

Nitrogen

All varieties responded significantly to the use of 125 pounds of nitrogen per acre. P.R. 903 gave the highest yields when 125 and 250 pounds of nitrogen were used per acre. The mean of the five crops shows a significant

increase in yield when 250 pounds of nitrogen per acre were used, as compared with 125 pounds (table 10). However, most of the increase was realized in the plant cane and first ratoon. The later ratoons did not show this significant increase. As presented in figure 2, the responses of the varieties to the nitrogen levels were very similar. The relative positions of the varieties were the same for the 0, 125, and 250 pounds of nitrogen per acre. Thus, P.R. 903 outyielded the other three varieties regardless of the fertility level.

Phosphorus

The response to phosphorus was slight, as was indicated before. Certain varieties responded more to phosphate fertilizers than others. P.R. 903 responded significantly to 300 pounds of P_2O_5 in the second ratoon (treatment 7 minus treatment 3) and 150 pounds in the third (treatment 4 minus treatment 3). P.O.J. 2878 and M. 317, however, showed no significant response to phosphorus applications. M. 275 showed a response to 150 pounds of P_2O_5 in the fourth ratoon only (treatment 4 minus treatment 3). However, the relative responses to P_2O_5 by the four varieties at various P_2O_5 levels were approximately the same as shown in figure 2.

Potassium

Variety P.R. 903 had the highest yields under 0, 150, and 300 pounds of K_2O per acre. None of the varieties treated responded significantly to potassium in the plant cane (table 10). P.O.J. 2878 gave significant yield increases with the use of 150 pounds of K_2O (treatment 4 minus treatment 3) for all ratoons except the fourth, where 300 pounds of K_2O were required. All ratoons of P.R. 903 gave significant increases in yields when 150 pounds of K_2O were applied, as compared to no potash, except for the second ratoon where 300 pounds of K_2O were needed. Varieties M. 275 and M. 317 did not respond to 150 pounds of K_2O per acre; 300 pounds per acre were needed for any significant yield increases. It would be more economical, therefore, to use P.R. 903, which needs only 150 pounds of K_2O per acre to obtain yields better than M. 317 with 300 pounds. As shown in figure 2, P.R. 903 gave higher yield responses at all potassium levels. Of the remaining three varieties, none was consistently in the lead at all potassium levels.

SUCROSE-PERCENT-CANE CONTENT

The use of nitrogen fertilizers did not significantly influence the sucrose content of any of the four varieties (table 11). The use of 300 pounds of nitrogen per acre (treatment 7) did not cause any significant decrease in the sucrose content of any of the varieties.

The application of phosphate fertilizers (treatments 3, 4, and 7) did not

TABLE 10.—*Mean yields in hundredweights of available 96° sugar for 4 varieties of sugarcane when grown at different fertilizer levels*

Treatment No.	Treatments in pounds per acre of—			Mean yields in hundredweights of available 96° sugar per acre					Mean of 5 crops
	N	P_2O_5	K_2O	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
				P.O.J. 2878					
1	0	300	300	125	84	92	92	110	101
2	125	300	300	178	116	112	125	137	134
3	250	0	300	194	133	119	124	126	139
4	250	150	300	200	134	123	121	131	142
5	250	300	0	188	123	104	112	108	126
6	250	300	150	190	138	121	125	119	139
7	250	300	300	194	136	117	126	131	141
Mean for all treatments				181	124	113	118	123	132
Significant difference needed between treatments of same crop:									
5-percent level				21	13	10	9	13	7
1-percent level				27	17	13	12	18	10
				P.R. 903					
1	0	300	300	133	90	82	86	96	98
2	125	300	300	209	137	106	127	150	146
3	250	0	300	273	146	108	119	148	159
4	250	150	300	256	146	117	132	146	159
5	250	300	0	242	137	110	104	124	143
6	250	300	150	256	150	113	125	144	158
7	250	300	300	252	147	121	128	153	160
Mean for all treatments				232	136	108	117	137	146
Significant difference needed between treatments of same crop:									
5-percent level				21	13	10	9	13	7
1-percent level				27	17	13	12	18	10
				M. 275					
1	0	300	300	118	79	79	74	104	91
2	125	300	300	181	117	102	102	138	128
3	250	0	300	202	122	100	101	118	128
4	250	150	300	207	115	109	104	131	133
5	250	300	0	210	116	95	100	116	127
6	250	300	150	202	115	100	95	119	126
7	250	300	300	216	128	108	106	131	138
Mean for all treatments				191	113	99	97	122	125

TABLE 10.—*Continued*

Treatment No.	Treatments in pounds per acre of—			Mean yields in hundredweights of available 96° sugar per acre					Mean of 5 crops
	N	P_2O_5	K_2O	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
Significant difference needed between treatments of same crop:									
5-percent level				21	13	10	9	13	7
1-percent level				27	17	13	12	18	10
M. 317									
1	0	300	300	118	83	78	81	98	92
2	125	300	300	207	119	107	118	129	136
3	250	0	300	236	130	108	120	133	145
4	250	150	300	230	134	111	117	139	146
5	250	300	0	216	130	102	108	119	135
6	250	300	150	216	122	106	109	129	137
7	250	300	300	226	137	107	121	135	145
Mean for all treatments				207	122	103	111	126	134
Significant difference needed between treatments of same crop:									
5-percent level				21	13	10	9	13	7
1-percent level				27	17	13	12	18	10

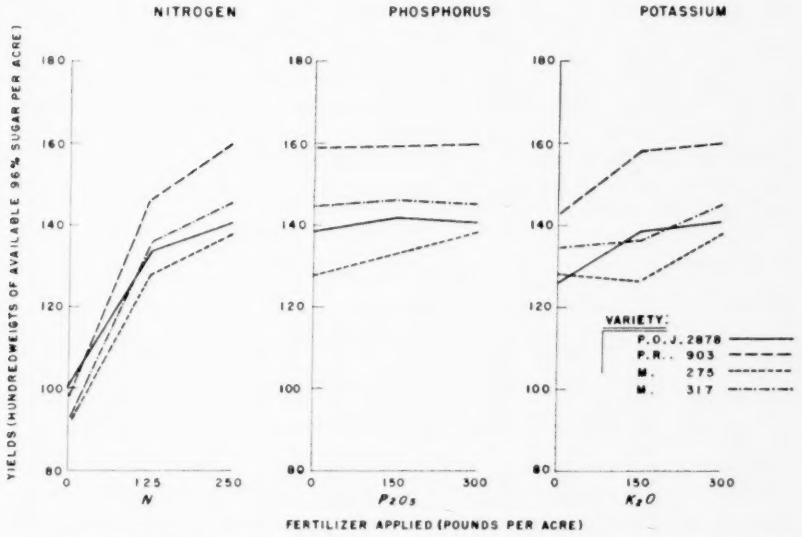

FIG. 2.—Yield response of the 4 sugarcane varieties to nitrogen, phosphorus, and potassium when used as fertilizers.

TABLE 11.—*Mean sucrose-percent-cane content for 4 varieties of sugarcane when grown at different fertilizer levels*

Treatment No.	Treatments in pounds per acre of—			Mean sucrose-percent-cane content					Mean of 5 crops
	N	P_2O_5	K_2O	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
				P.O.J. 2878					
1	0	300	300	12.63	11.29	11.11	11.78	12.90	11.94
2	125	300	300	12.89	11.27	11.24	11.80	12.82	12.01
3	250	0	300	12.16	11.51	11.05	11.46	12.40	11.71
4	250	150	300	12.60	11.66	11.22	11.32	12.36	11.83
5	250	300	0	12.20	11.21	10.31	10.31	12.07	11.34
6	250	300	150	12.42	11.31	10.91	11.54	12.11	11.66
7	250	300	300	12.42	11.83	11.02	11.67	12.41	11.87
Mean for all treatments				12.47	11.44	10.98	11.50	12.44	11.77
Significant difference between treatments of same crop:									
5-percent level				0.71	0.64	0.90	0.56	0.65	0.70
1-percent level				.94	.85	1.19	.74	.86	.92
				P.R. 903					
1	0	300	300	12.37	11.28	10.88	11.88	12.88	11.86
2	125	300	300	12.73	11.78	11.18	12.07	13.19	12.19
3	250	0	300	13.25	11.41	10.30	11.78	12.88	11.92
4	250	150	300	12.98	11.62	10.94	12.04	12.72	12.06
5	250	300	0	12.69	11.26	10.72	11.15	12.05	11.57
6	250	300	150	12.53	11.75	10.59	11.54	12.45	11.77
7	250	300	300	12.36	11.71	10.86	11.94	12.94	11.96
Mean for all treatments				12.70	11.54	10.78	11.77	12.73	11.91
Significant difference between treatments of same crop:									
5-percent level				0.71	0.64	0.90	0.56	0.65	0.70
1-percent level				.94	.85	1.19	.74	.86	.92
				M. 275					
1	0	300	300	12.15	11.44	10.80	11.39	12.87	11.73
2	125	300	300	12.80	11.47	10.98	11.51	12.91	11.94
3	250	0	300	12.41	11.56	10.63	11.34	12.29	11.65
4	250	150	300	12.27	10.89	10.79	11.43	12.49	11.57
5	250	300	0	12.70	10.90	10.34	11.31	12.35	11.52
6	250	300	150	11.97	10.85	10.40	10.97	12.17	11.27
7	250	300	300	12.86	11.31	10.76	11.43	12.22	11.72
Mean for all treatments				12.45	11.20	10.67	11.34	12.47	11.63

TABLE 11.—*Continued*

Treatment No.	Treatments in pounds per acre of—			Mean sucrose-percent-cane content					Mean of 5 crops
	N	P_2O_5	K_2O	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	
Significant difference between treatments of same crop:									
5-percent level				0.71	0.64	0.90	0.56	0.65	0.70
1-percent level				.94	.85	1.19	.74	.86	.92
M. 317									
1	0	300	300	12.51	11.50	11.02	12.04	12.78	11.97
2	125	300	300	13.23	11.71	10.77	11.78	12.55	12.01
3	250	0	300	12.71	11.69	10.48	11.88	12.81	11.95
4	250	150	300	12.47	11.32	10.71	11.47	12.59	11.72
5	250	300	0	12.69	10.96	10.21	10.85	11.90	11.32
6	250	300	150	12.71	10.98	10.53	11.06	12.32	11.52
7	250	300	300	12.96	11.53	10.47	11.64	12.79	11.88
Mean for all treatments				12.78	11.39	10.60	11.53	12.53	11.77
Significant difference between treatments of same crop:									
5-percent level				0.71	0.64	0.90	0.56	0.65	0.70
1-percent level				.94	.85	1.19	.74	.86	.92

influence significantly the sucrose content of the varieties tested. The varieties responded with different intensities to the application of potassium. M. 275 did not significantly change in sucrose content. There was a significant increase in the sucrose content of P.O.J. 2878 in the third ratoon only when 300 pounds of K_2O were applied. Beginning with the third ratoon, P.R. 903 and M. 317 significantly increased in sucrose content when 300 pounds of K_2O per acre were used (table 11, treatment 7 minus treatment 5).

TONS OF CANE PER ACRE

Table 12 shows a variety response at different fertilizer levels similar to that observed for hundredweights of sugar per acre.

RELATIVE RESPONSE TO FERTILIZERS

REDUCTION IN YIELDS FROM OMISSION OF A FERTILIZER ELEMENT

The major fertilizer elements (nitrogen, phosphorus, and potassium) are necessary for maximum sugarcane yields. The response to these three elements varies, depending on the quantities already present in the soil, their form and availability. In table 13 the relative response to the ferti-

TABLE 12.—*Mean yields in tons of cane per acre for 4 varieties of sugarcane when grown at different fertilizer levels*

Treatment No.	Treatments in pounds per acre of—			Mean yields in tons of cane per acre					
	N	P_2O_5	K_2O	Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	Mean of 5 crops
				P.O.J. 2878					
1	0	300	300	49.5	37.5	41.4	39.1	42.6	42.3
2	125	300	300	69.1	51.5	49.9	53.0	53.4	56.0
3	250	0	300	79.8	57.8	53.8	54.1	51.0	59.4
4	250	150	300	79.4	57.5	54.8	53.4	53.0	60.0
5	250	300	0	77.1	54.9	50.4	51.4	45.0	56.0
6	250	300	150	76.5	60.1	55.5	54.2	49.1	59.6
7	250	300	300	78.1	57.5	53.1	54.0	52.8	59.4
Mean for all treatments				72.6	54.2	51.5	51.3	49.4	56.1
				P.R. 903					
1	0	300	300	54.0	40.0	37.7	36.2	37.3	41.3
2	125	300	300	82.1	58.1	47.4	52.6	56.9	59.9
3	250	0	300	103.0	64.0	52.4	47.1	57.5	66.7
4	250	150	300	98.6	63.0	53.5	54.8	57.4	65.9
5	250	300	0	95.4	61.0	51.3	46.6	51.5	61.8
6	250	300	150	102.2	63.8	53.8	54.2	57.8	67.1
7	250	300	300	101.9	63.0	56.0	53.6	59.1	66.9
Mean for all treatments				91.3	59.0	50.0	49.7	53.8	61.3
				M. 275					
1	0	300	300	48.6	34.5	36.6	32.5	40.4	39.0
2	125	300	300	70.7	51.0	46.4	44.3	53.5	53.6
3	250	0	300	81.4	53.0	47.0	44.5	48.0	55.0
4	250	150	300	84.4	53.0	51.0	45.5	52.4	57.5
5	250	300	0	82.7	52.2	46.0	44.2	47.0	55.1
6	250	300	150	84.4	53.0	48.1	43.3	49.0	55.9
7	250	300	300	84.0	56.6	50.1	46.4	53.6	59.0
Mean for all treatments				77.0	50.5	45.1	43.0	48.9	54.0
				M. 317					
1	0	300	300	47.2	36.1	35.4	34.0	38.3	38.4
2	125	300	300	78.2	53.1	50.0	50.1	51.4	56.6
3	250	0	300	93.0	55.6	52.0	51.0	52.0	61.0
4	250	150	300	92.2	59.2	52.0	51.0	55.2	62.3
5	250	300	0	85.1	59.3	50.0	49.8	50.0	59.6
6	250	300	150	85.0	55.6	50.3	48.0	52.3	59.5
7	250	300	300	87.1	59.4	51.1	52.0	53.0	61.0
Mean for all treatments				81.0	53.6	48.6	48.1	50.3	57.0

TABLE 13.—*The percentage reduction in yield of available 96° sugar per acre by 4 sugarcane varieties attributable to the omission of nitrogen, phosphorus, or potassium*

Variety and crop	Reduction in yield from omission of—		
	Nitrogen	Phosphorus	Potassium
	Percent	*Percent*	*Percent*
P.O.J. 2878:			
Plant cane	36	0	3
First ratoon	38	2	10
Second ratoon	21	2	11
Third ratoon	27	2	11
Fourth ratoon	16	4	18
Mean of 5 crops	28	1	11
P.R. 903:			
Plant cane	47	8	4
First ratoon	39	1	7
Second ratoon	32	11	9
Third ratoon	33	7	19
Fourth ratoon	37	3	19
Mean of 5 crops	38	3	12
M. 275:			
Plant cane	45	6	3
First ratoon	38	5	9
Second ratoon	27	7	12
Third ratoon	30	5	6
Fourth ratoon	21	10	11
Mean of 5 crops	32	7	8
M. 317:			
Plant cane	48	4	4
First ratoon	39	5	5
Second ratoon	27	1	5
Third ratoon	33	1	11
Fourth ratoon	27	1	12
Mean of 5 crops	35	1	7
Mean of four varieties:			
Plant cane	44	2	3
First ratoon	39	3	8
Second ratoon	27	4	9
Third ratoon	31	3	12
Fourth ratoon	26	5	15
Mean of 5 crops	33	3	9

lizer elements is presented in the form of the reduction in yields caused by omission of one of them. The reduction was calculated from the yield at the highest fertilizer levels, as compared with the no-fertilizer level.

As mentioned earlier, the greatest reduction in yield occurred when nitrogen was omitted. It is interesting to note that the reduction in yield decreased with the number of ratoons. The mean yield of the four varieties was reduced 44 percent in plant cane, 39 in first ratoon, and only 26 percent by the fourth ratoon. It appears that the greatest benefit is derived from high nitrogen applications in the plant cane and new ratoons, and less in the older ratoons.

The reduction in yield from the omission of phosphorus was only 3 percent for the whole experiment. The yield of M. 275 was reduced most when phosphorus was omitted.

When potassium was omitted there was a reduction in yield of 9 percent for the whole experiment. For the mean of the four varieties, the reduction for plant cane was 3 percent, which rose to 15 percent for the fourth ratoon. The fourth ratoon indicated more need for potash than did the plant cane.

PERCENTAGE OF MAXIMUM YIELDS

The concept of maximum yields is one closely associated with the work of Mitscherlich. The maximum yield represents the hypothetical yield obtainable with unlimited increases in the fertilizer nutrient. This concept has been both attacked and defended with much zeal. The use of maximum yields is debatable as an exact measure of crop yields; however, as a guide in indicating the relative increases to be obtained from fertilizer increments it has practical value. It is of particular value in indicating how useful heavy fertilizer applications are in increasing yields.

The maximum potential yields of the mean of the five crops for the four varieties were calculated, using the modified formula of Capó (2), and are presented in table 14. Certain entries under phosphorus and potassium were omitted because the yield data could not be applied to the modified equation used.

When no nitrogen was applied the yield of available 96° sugar was only 64 percent of the possible maximum yield for the mean of the four varieties. When 125 pounds of nitrogen per acre were used, the yield was 91 percent of the possible maximum yield for this experiment. From this it appears that the first 125 pounds of nitrogen are of decided value in increasing cane yields. However, the use of an additional 125 pounds of nitrogen gives an increase of only 7 percent, from 91 to 98 percent of the maximum. The decision as to whether an additional 7 percent of cane makes the use of 125 pounds of nitrogen per acre profitable is one for the individual grower to make. However, it is very clear that, under the conditions of the experi-

ment, the use of over 250 pounds of nitrogen per acre would be of no value to the grower.

Yields were 98 percent of maximum when phosphorus was omitted from one fertilizer used. The use of 150 pounds of P_2O_5 gave an increase of 1 percent only, and 300 pounds of P_2O_5 produced maximum yields for the experiment. The use of even 150 pounds of P_2O_5 was unprofitable in this experiment.

TABLE 14.—*The percentage of maximum yields of available 96° sugar per acre obtained for 4 varieties of sugarcane when grown at different fertilizer levels*

Variety	Fertilizer element	Maximum yield in available 96° sugar	Fertilizer applied per acre		
			None	125 lbs. N and 150 lbs. of P_2O_5 and of K_2O	250 lbs. of N and 300 lbs. of P_2O_5 and of K_2O
		Hundredweights	*Percent*	*Percent*	*Percent*
P.O.J. 2878	Nitrogen	143	71	94	99
	Phosphorus	—	—	—	—
	Potassium	141	90	99	100
P.R. 903	Nitrogen	166	59	88	97
	Phosphorus	—	—	—	—
	Potassium	160	89	99	100
M. 275	Nitrogen	142	64	90	97
	Phosphorus	—	—	—	—
	Potassium	—	—	—	—
M. 317	Nitrogen	147	63	92	99
	Phosphorus	—	—	—	—
	Potassium	—	—	—	—
Mean of 4 varieties	Nitrogen	149	64	91	98
	Phosphorus	147	98	99	100
	Potassium	150	90	99	100

Ninety percent of the maximum yield was obtained when potassium was not applied (see table 14). The addition of 150 pounds of K_2O per acre produced 99 percent of the maximum yield. In practice the use of more than 150 pounds of K_2O per acre is neither warranted nor economical.

FOLIAR DIAGNOSIS

THE NUTRIENT CONTENT OF THE SUGARCANE LEAF

Beginning with second ratoon, leaf samples were taken at a cane age of 3 months. The analysis of the leaf samples is given in table 15.

TABLE 15.—*Nitrogen phosphorus, and potassium content of dry leaf samples taken from 4 varieties of sugarcane growing at different fertilizer levels*

Treatments in pounds per acre of—			Fertilizer element	Content of leaf samples of—				Mean of 4 varieties
N	P_2O_5	K_2O		P.O.J. 2878	P.R. 903	M. 275	M. 317	
				Second ratoon				
				Percent	*Percent*	*Percent*	*Percent*	*Percent*
0	300	300	Nitrogen	1.35	1.59	1.29	1.49	1.43
125	300	300		1.50	1.86	1.52	1.67	1.64
250	300	300		1.70	2.02	1.88	1.75	1.84
250	0	300	Phosphorus	.19	.21	.20	.21	.20
250	150	300		.24	.24	.23	.27	.25
250	300	300		.25	.26	.24	.27	.26
250	300	0	Potassium	1.54	1.52	1.58	1.61	1.56
250	300	150		1.60	1.66	1.75	1.66	1.67
250	300	300		1.72	1.67	1.85	1.74	1.75
				Third ratoon				
0	300	300	Nitrogen	1.52	1.64	1.65	1.55	1.59
125	300	300		1.76	1.73	1.81	1.75	1.76
250	300	300		1.84	1.84	1.91	1.74	1.83
250	0	300	Phosphorus	.21	.21	.22	.20	.21
250	150	300		.22	.22	.25	.22	.23
250	300	300		.24	.25	.26	.24	.25
250	300	0	Potassium	1.50	1.69	1.57	1.63	1.60
250	300	150		1.58	1.89	1.65	1.68	1.70
250	300	300		1.66	1.87	1.76	1.80	1.77
				Fourth ratoon				
0	300	300	Nitrogen	1.17	1.17	1.24	1.26	1.21
125	300	300		1.39	1.42	1.45	1.46	1.43
250	300	300		1.39	1.46	1.42	1.44	1.43
250	0	300	Phosphorus	.17	.19	.17	.17	.18
250	150	300		.19	.19	.19	.20	.19
250	300	300		.22	.21	.24	.22	.22
250	300	0	Potassium	1.72	1.60	1.62	1.92	1.72
250	300	150		1.89	1.99	1.99	1.94	1.95
250	300	300		2.36	2.30	2.19	2.43	2.32

TABLE 15.—*Continued*

Treatments in pounds per acre of—			Fertilizer element	Content of leaf samples of—				Mean of 4 varieties
N	P_2O_5	K_2O		P.O.J. 2878	P.R. 903	M. 275	M 317	
Mean of 3 crops								
				Percent	*Percent*	*Percent*	*Percent*	*Percent*
0	300	300	Nitrogen	1.35	1.47	1.39	1.43	1.41
125	300	300		1.55	1.67	1.59	1.63	1.61
250	300	300		1.64	1.77	1.74	1.64	1.70
250	0	300	Phosphorus	.19	.20	.20	.19	.20
250	150	300		.22	.22	.22	.23	.22
250	300	300		.24	.24	.25	.24	.24
250	300	0	Potassium	1.59	1.60	1.59	1.72	1.63
250	300	150		1.69	1.85	1.80	1.76	1.77
250	300	300		1.91	1.95	1.93	1.99	1.95

Nitrogen

For all varieties and ratoons sampled, the leaf nitrogen increased with increasing applications of nitrogen fertilizer to the soil. With no nitrogen added to the soil, the mean nitrogen content of leaf for the four varieties was 1.41 percent for the mean of the three ratoons. When 125 pounds of nitrogen per acre were added to the soil, it rose to 1.61 percent; when 250 pounds of nitrogen were used, the leaf nitrogen content was 1.70 percent.

Table 15 shows more variation in leaf nitrogen content among the ratoons (year sampled) than for varieties within a given ratoon. This fluctuation will be discussed more thoroughly under "Correction Factors."

Phosphorus

The concentration of phosphorus in the leaf increased with phosphate fertilizer additions. The increase was not very large but was consistent. The cane grown without phosphorus had a mean leaf content of 0.20 percent of phosphorus; it varied only from 0.17 to 0.22 percent. With the addition of P_2O_5 up to rates of 300 pounds per acre, the phosphorus content of leaf rose to a mean of 0.24 percent. The seasonal variation in the phosphorus content of the leaf was greater than the varietal variation.

Potassium

The potassium content of the sugarcane leaf was generally a little higher than the nitrogen content. There was variation attributable to both variety

and season. The no-potassium treatment for the mean of three crops resulted in a mean potassium content of the leaf of 1.63 percent; this increased to 1.95 percent with the addition of 300 pounds of K_2O per acre.

CORRECTION FACTORS

The accumulated data for the leaf analyses for 3 years (see table 15) show an appreciable yearly fluctuation. The third-ratoon levels of the no-nitrogen treatments are the highest, with the fourth ratoon having the lowest values. As the same fertilizer and cultural treatments were used for all crops, these fluctuations were for the most part caused climatically. This climatic factor can be divided into temperature, light, and rainfall. The seasonal variations in temperature and light were not recorded for this experiment and corrections could not be made for these.

The influence of rainfall on the variation of the nutrient in the leaf was determined using the rainfall data for the area. In figure 3, *A*, the rainfall for the period from time of cutting of the previous ratoon to the taking of the leaf sample was plotted against the percentage of nitrogen in the leaves. The regression values for the equations of the relationship were significant for the mean of the four varieties and for variety P.O.J. 2878. The equations obtained were:

Mean of 4 varieties	$Y = 0.96 + 0.021\ x$
M. 275	$Y = .95 + .021\ x$
P.O.J. 2878	$Y = .91 + .020\ x$
M. 317	$Y = 1.07 + .017\ x$
P.R. 903	$Y = .94 + .024\ x$

Thus, for every 10 inches of rain falling in the period from harvest to leaf-sampling time, there was a mean increase of 0.21 percent of nitrogen in the leaf sample.

To determine whether rainfall 1 week prior to leaf sampling influenced the leaf nitrogen these factors were plotted graphically (see figure 3, B). One inch of rain during the week prior to sampling increased the leaf nitrogen 0.33 percent.

This correction for rainfall permits the adjustment of the nutrient values of the leaf to the same basis, and allows a more accurate fit of leaf-nutrient values to yields. If we assume a basis of 20 inches of rain for the period from time of planting or cutting to taking the leaf sample, we can adjust the nitrogen values of table 15 to that basis regardless of rainfall variation. The adjusted data are given in table 16. When the data in these tables are compared it is seen that the correction for rainfall has adjusted the values for each year to about the same levels.

INTERPRETATION OF FOLIAR-ANALYSIS DATA

With increasing amounts of the fertilizer elements, the concentration of that fertilizer element in the sugarcane leaf increased (table 15). For nitrogen in almost all cases, the application of 125 and 250 pounds of nitrogen

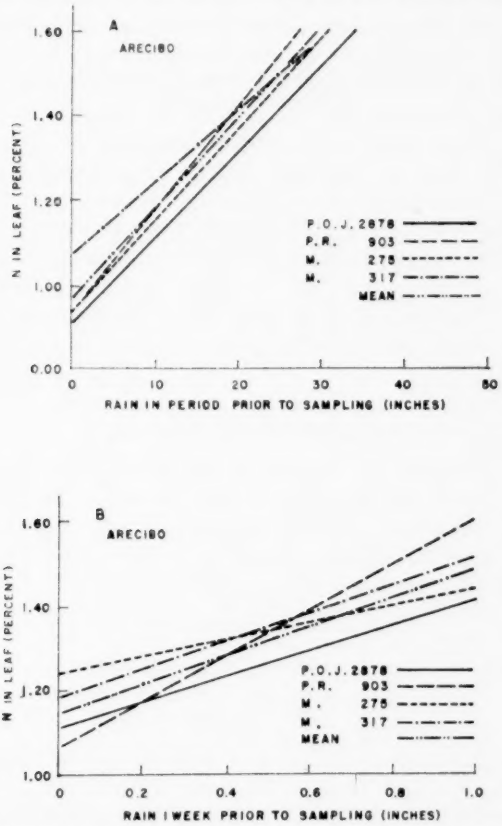

FIG. 3.—A, Rainfall during the period from time of cutting the previous ratoon to the taking of the leaf sample, as compared with percentage nitrogen in the leaf; B, rainfall during the period 1 week prior to taking the leaf sample as compared with percentage nitrogen in the leaf.

fertilizer per acre produced significant yield increases. Phosphorus applications produced no yield increases. Potassium fertilizers gave significant yield increases in some instances only. If we use the criteria of a significant increase in yield caused by a particular fertilizer application as a basis of selection, we can select leaf concentrations corresponding to these signifi-

cant applications. Nutrient concentrations in the leaf corresponding to fertilizer applications which produced no significant increases in yields may be judged to indicate no response to fertilizers.

Using the corrected data of table 16, we see that, in general, values of approximately 1.40 percent nitrogen in the leaf or below are associated with the addition of no nitrogen, from 1.40 to 1.60 with applications of up

TABLE 16.—*Nitrogen content of dry leaf samples of 4 varieties of sugarcane corrected for rainfall differences*[1]

Crop	Content of leaf samples of—				Mean of 4 varieties
	P.O.J. 2878	P.R. 903	M. 275	M. 317	
No nitrogen[2]					
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Second ratoon	1.27	1.49	1.21	1.42	1.35
Third ratoon	1.31	1.40	1.44	1.35	1.38
Fourth ratoon	1.32	1.33	1.39	1.40	1.36
Mean of 3 crops	1.30	1.41	1.34	1.39	1.36
125 pounds of nitrogen per acre					
Second ratoon	1.42	1.76	1.44	1.60	1.56
Third ratoon	1.55	1.49	1.60	1.55	1.55
Fourth ratoon	1.54	1.58	1.60	1.60	1.58
Mean of 3 crops	1.50	1.61	1.55	1.58	1.56
250 pounds of nitrogen per acre					
Second ratoon	1.62	1.92	1.80	1.68	1.76
Third ratoon	1.63	1.60	1.70	1.54	1.62
Fourth ratoon	1.54	1.62	1.57	1.58	1.53
Mean of 3 crops	1.60	1.71	1.69	1.60	1.64

[1] All nitrogen values corrected to a basis of 20 inches of rainfall for period from cutting period of previous ratoon to time of leaf sampling. Original rainfall values in inches were 24, 30, and 13 for ratoons 2, 3, and 4, respectively.

[2] All treatments received 300 pounds of P_2O_5 and K_2O per acre, respectively.

to 125 pounds of nitrogen per acre, and from 1.60 to 1.70 percent leaf nitrogen with applications of 250 pounds. Therefore, it may be assumed that cane having leaf-nitrogen (when adjusted for rainfall) values below 1.40 percent would give significant higher yields of cane if fertilizer were applied. If leaf values are between 1.60 and 1.70 percent, it may be assumed that the addition of 125 pounds of nitrogen to the soil would give some

increase in cane yield but not as great a one as for values below 1.60 percent. If the leaf nitrogen concentrations are above 1.70 percent it can be assumed that nitrogen fertilizers would produce no significant higher yields of sugarcane. Values below 1.40-percent leaf nitrogen indicate a more severe need of nitrogen, and 250 pounds would prove of more value than 125 pounds per acre.

As the annual fluctuation for phosphorus was not too great, we may then use values unadjusted for rainfall as a guide. If the leaf contains above 0.17 percent of phosphorus, this may be regarded as indicating that the cane would not respond appreciably to phosphorus fertilizers.

When leaf potassium values for sugarcane (adjusted for rainfall) are lower than 1.70 percent, this indicates that significantly greater cane yields can be expected if potash fertilizers are applied. If the leaf potassium values are above 1.90 percent no significant responses in yield of cane should be expected with potash applications.

The mathematical relationship between plant composition and crop as developed by Capó for hegari sorghum (2) was modified for sugarcane. The relationship was expressed by

$$Yr = A \text{ arc tan. percent } Nu + B$$

where Yr is the relative yield, *arc tan. per cent* Nu is the arc whose tangent has the same value as the percent nutrient content of the leaf on a dry-weight basis, and A and B are constants of the equation. This equation in its preliminary form has given significant relationships for the three ratoons samples. The details of this portion of the work and its results will be presented in a forthcoming publication.

Practical Recommendations

VARIETIES

Of the four sugarcane varieties tested, P.O.J. 2878, P.R. 903, M. 275, and M. 317, P.R. 903 was best, and yielded the most tons of cane per acre. There was no significant difference in sucrose percent cane between the four varieties. P.R. 903 gave the highest yields in hundredweights of 96° available sugar per acre and should be used in preference to the other three varieties.

FERTILIZERS

The response to fertilizer applications was greatest for nitrogen, less for potassium, and least for phosphorus. For sugarcane grown on Coloso silty clay and similar soils in the Arecibo area, the fertilizer recommendations are:

Plant cane

Nitrogen—125 to 250 pounds of N per acre
Phosphorus—40–50 pounds P_2O_5 per acre
Potassium—100 pounds of K_2O per acre

Ratoons

Nitrogen—125 pounds of N per acre
Phosphorus—40–50 pounds O_2O_5 per acre
Potassium—150 pounds of K_2O per acre

Summary

A variety-fertilizer experiment using four varieties at seven fertilizer levels was carried on for a plant sugarcane and four ratoons. The major results were:

1. Nitrogen gave the highest yield increases in hundredweights of 96° available sugar per acre.

2. Phosphate fertilizers did not increase the yields of sugar.

3. Potassium fertilizers did increase the yields of sugar per acre.

4. The application of nitrogen and phosphorus did not influence sucrose concentrations in the cane. The omission of potassium did decrease the sucrose content of the cane significantly.

5. Variety P.R. 903 gave the highest yields of sugar per acre as compared with P.O.J. 2878, M. 275, and M. 317. The yields of M. 317 and P.O.J. 2878 were about equal, and M. 275 gave the lowest yields.

6. The varieties maintained their relative yielding power when tested at various fertilizer levels. Except for the no-fertilizer level, P.R. 903 maintained its significant lead in yield at all levels of fertilizer application. There was no significant interaction between varieties and fertilizers.

7. The reductions in yields from the omission of a fertilizer element for the mean of five crops were 33, 3, and 9 percent for nitrogen, phosphorus, and potassium, respectively.

8. Analysis of leaf samples revealed that corrections must be made for rainfall to prevent a yearly variation in the data. When corrected for rainfall variations, values of 1.40 percent nitrogen (dry weight of the leaf) or below were associated with low cane yields, and values of 1.60 percent or over with high yields. For phosphorus, values above 0.17 percent phosphorus in the leaf at a cane age of 3 months may be regarded as indicating no appreciable need for phosphate fertilizers. Potassium values of 1.70 percent potassium in the leaf or less indicate a need for potash, and 1.90 percent or greater, none.

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THE RESPONSE OF SUGARCANE IN PUERTO RICO TO VARIOUS NITROGEN SOURCES

George Samuels, Pablo Landrau, Jr., and Bernardo G. Capó[1]

Introduction

Nitrogen is of great importance in the fertilization of agricultural crops in Puerto Rico. The response in higher yields is greater for nitrogen than for any other fertilizer element used. Extensive experimentation by the Agricultural Experiment Station of the University of Puerto Rico and actual practices of the farmers have proven the truth of these statements.

Up to and including the present, ammonium sulfate has been the chief source of fertilizer nitrogen used in Puerto Rico. By comparison, the use of sodium nitrate, urea compounds, and ammonium nitrate has been minor. This is clearly shown in table 1 where ammonium sulfate is the leading nitrogen source imported for fertilizer production, despite the decrease in the 1941–45 war period when imports were limited by restrictions in shipping space.

During World War II, attention was called to the need of data on the relative efficiency of nitrogen sources. Sharp restrictions on both production and shipping of fertilizers demanded the utmost efficiency in fertilizer materials, particularly nitrogen-bearing ones. Ammonium nitrate also appeared on the market at that time when produced in excess of war requirements, and some of this material was assigned for use as a fertilizer nitrogen carrier. The introduction of ammonium nitrate as a substitute for ammonium sulfate made it advisable to determine whether the former was as effective as the latter for sugarcane and other crops in Puerto Rico.

With these points in mind experimentation was begun by the Agronomy and Horticulture Department of the Agricultural Experiment Station to study specifically whether ammonium nitrate could be substituted for ammonium sulfate as a nitrogen fertilizer in Puerto Rico. Interest was also renewed in the comparison of the effectiveness of different nitrogen sources as fertilizer materials. Because over 70 percent[2] of the fertilizer used in Puerto Rico is applied to sugarcane, field experiments were performed with this crop to make such comparisons.

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[2] The mean for the period 1942–49 compiled from data taken from (2).

Earlier Work

Experiments with various forms of nitrogen fertilizers in Puerto Rico have been limited. Fernández García (3)[3] working with sugarcane on a Ponce loam soil at Colonia Laurel, Central Mercedita, Ponce, compared ammonium sulfate and sodium nitrate as a nitrogen source. A summary of his results is presented in table 2. There was no significant difference in yield of cane between the ammonium sulfate and sodium nitrate treatments. Méndez and Chardón (6) conducted experiments on sugarcane over a period of 5 years to compare ammonium sulfate, sodium nitrate, and calcium cyanamide as nitrogen sources. The results are given in table 3. There was

Table 1.—*Nitrogen fertilizers imported into Puerto Rico during the period 1936–49*[1]

Fiscal year	Nitrogenous material in tons (2,000 pounds) of—					
	Cyanamide	Sodium nitrate	Ammonium sulfate	Ammonium nitrate	Uramon	Ammonium superphosphate
1936–37	1,998	367	101,520	—	—	—
1937–38	1,359	367	87,879	—	—	—
1938–39	1,019	162	59,318	—	—	—
1939–40	2,012	1,635	82,978	—	—	—
1940–41	3,720	435	81,133	—	3,755	3,133
1941–42	776	250	67,299	—	100	4,094
1942–43	—	—	32,839	—	—	—
1943–44	100	—	65,826	25,904	—	9,689
1944–45	105	—	73,494	21,963	5,200	—
1945–46	1,794	70	70,769	16,301	—	2,208
1946–47	3,342	298	83,899	30,466	—	11,986
1947–48	2,796	794	69,480	19,098	--	40,978
1948–49	3,082	148	91,080	8,023	--	27,886

[1] Data compiled from the Departamento de Agricultura y Comercio de Puerto Rico, Laboratorio Químico, Informes Anuales, 1936–37 a 1948–49.

no significant difference in yield of cane that could be attributed to any of the nitrogen sources used.

The annual reports of the Agricultural Experiment Station of Puerto Rico record two experiments with organic-nitrogen sources. The first, reported by López-Domínguez (5), compared tankage with ammonium sulfate on sugarcane from 1912 to 1917. Tankage at the rate of 600 pounds per acre was tested against ammonium sulfate at the rate of 60 pounds per acre, both treatments being made with and without lime. The yields of cane were almost the same for limed and unlimed plots, regardless of nitrogen

[3] Numerals in parentheses refer to Literature Cited, p. 239.

source. The average for 4 years was 23.0 and 23.4 tons cane per acre for the limed ammonium sulfate and tankage treatments, respectively, and 20.3 and 20.1 for the unlimed, respectively. Clavell (1) reports a 9-year experiment in which *Crotalaria striata* was used as a green-manure crop for sugarcane. The crotalaria was plowed under when in bloom, and the sugarcane was planted 3 to 4 months later. A plant cane and ratoon were

TABLE 2.—*Relative effect of ammonium sulfate and sodium nitrate sources of nitrogen on yields of sugarcane*[1]

Nitrogen carrier	Treatment in pounds per acre of—			Yield in tons of cane per acre		
	NH_3	P_2O_5	K_2O	Plant cane	First ratoon	Mean of two crops
Ammonium sulfate	90	60	60	33.3	24.4	28.7
Sodium nitrate	90	60	60	31.7	26.0	28.8
Ammonium sulfate	120	60	60	33.2	26.8	30.0
Sodium nitrate	120	60	60	32.2	26.6	29.4
Ammonium sulfate	150	60	60	32.3	25.2	29.3
Sodium nitrate	150	60	60	32.4	27.0	29.7
Ammonium sulfate	180	60	60	37.2	28.4	32.8
Sodium nitrate	180	60	60	34.5	27.8	31.1
Check	0	60	60	27.8	19.6	23.8
Least significant difference at:						
5 percent				7.4	9.5	6.4
1 percent				9.9	12.8	8.7

[1] Compiled from the field data of the experiment of Fernández-García a summary of which is given in (3).

TABLE 3.—*Effect of different nitrogen carriers on yields of sugarcane*[1]

Nitrogen carrier	Yield of cane in tons per acre in—					
	1936	1937	1938	1939	1940	5-year average
Calcium cyanamide	60.1	35.4	33.5	32.8	27.1	37.8
Ammonium sulfate	62.1	36.0	33.3	31.1	27.8	38.1
Sodium nitrate	64.3	34.7	32.2	32.3	28.0	38.3

[1] Compiled from field data of an experiment by Méndez and Chardón (6).

grown before the next planting of crotalaria. No significant difference in yield took place as compared with cane on which the customary inorganic fertilizer was used in which ammonium sulfate was the nitrogen source.

RECENT EXPERIMENTS

Recent sugarcane experiments have been conducted on a Fraternidad clay at Santa Rita, Guánica; a Coto clay at Isabela Substation; and a

Vega Alta clay loam at Río Piedras. The results of these experiments will be taken up individually.

The experiment performed at Santa Rita, Guánica, is summarized in table 4. There was no significant difference between the nitrogen sources used, whether in one application or two. As a check treatment in which no nitrogen was applied was not included in this experiment, possibly the lack of differential response to the different nitrogen sources is attributable to the fact that the soil contained sufficient nitrogen for the production of maximum yield.

The Isabela Substation experiment with sugarcane consisted in comparing ammonium sulfate and ammonium nitrate as nitrogen sources. The plant cane showed no significant differences in yield that could be attributed to the nitrogen source used (see table 5). The yields under the

TABLE 4.—*Ammonium nitrate versus ammonium sulfate as a nitrogen source for sugarcane, Santa Rita, Guánica, 1944–45*

Treatment	Mean yield of 15 replicates in hundredweights of sugar per acre
Ammonium nitrate applied once at the rate of 200 pounds NH_3 per acre	91.8
Ammonium sulfate at the same rate	100.1
Ammonium nitrate applied twice at rate of 100 pounds NH_3 per acre per application	97.7
Ammonium sulfate at the same rate	94.8
Least significant difference between two means at:	
5 percent	10.4
1 percent	13.9

ammonium sulfate treatment were significantly higher than those when no nitrogen was used. The omission of ammonium sulfate reduced yields 14 percent, of ammonium nitrate, 7 percent. There was no response to phosphorus or potassium when nitrogen was omitted.

In the first ratoon crop of this experiment, ammonium sulfate gave yields higher than ammonium nitrate, which were significant at the 1-percent point. Both nitrogen sources gave yields significantly higher than the no-nitrogen treatment. The reduction in yield from the omission of ammonium sulfate was 34 percent, from the omission of ammonium nitrate, 20 percent.

In the first sugarcane experiment at Río Piedras ammonium sulfate, ammonium nitrate in one and two applications, and Uramon were compared. The experiment comprised a plant cane and two ratoons. The results in terms of yields of available 96° sugar are summarized in table 6. In all 3 crops there was a significant difference in yield between the no-nitrogen

and the nitrogen treatments. There was no significant difference in yield whether ammonium nitrate was used in one or two applications. This was

TABLE 5.—*A comparison of ammonium sulfate and ammonium nitrate as sources of nitrogen for sugarcane, Isabela Substation, 1944-46*

Nitrogen carrier	Treatment in pounds per acre of—			Mean yield of 18 replications in hundredweights of sugar per acre	
	NH_3	P_2O_5	K_2O	Plant cane 1944–45	First ratoon 1945–46
None	0	0	0	89.4	—
Do.	0	72	120	88.0	54.0
Ammonium sulfate	168	72	120	102.7	78.5
Ammonium nitrate	168	72	120	94.7	67.3
Ammonium sulfate	168	0	0	—	68.7
Least significant difference between any two means at:					
5 percent				10.2	8.6
1 percent				13.6	11.5

TABLE 6.—*A comparison of the efficiency of different nitrogen sources on available 96° sugar at Río Piedras*

[Yields of available 96° sugar]

Nitrogen carrier	Treatment in pounds per acre of—			Mean yield of 16 replications in hundredweights of available 96° sugar per acre			
	NH_3	P_2O_5	K_2O	Plant cane, 1944–45	First ratoon, 1945–46	Second ratoon, 1946–47	Mean yield of 3 crops
None	0	50	50	58	66	100	75
Ammonium sulfate	250	50	50	86	86	132	101
Ammonium nitrate, one application	250	50	50	88	83	126	99
Ammonium nitrate, two applications	250	50	50	79	84	123	96
Uramon	250	50	50	87	83	122	97
Least significant difference at:							
5 percent				7.0	7.0	9.9	6.2
1 percent				9.3	9.4	13.1	8.2

also true of ammonium sulfate in the experiment performed at Guánica (see table 4).

The available 96° sugar as percent cane was not significantly different regardless of the treatment used (see table 7), though lack of nitrogen lowered yields in the plant cane. This difference was significant only at

the 5-percent point. The results in table 7 indicate clearly that, for this experiment, the nitrogen source used did not adversely affect the sucrose content of the cane. Failure of high-nitrogen treatments to lower the sucrose content of cane has occurred before in other experiments performed at the Station. The often-stated belief that high-nitrogen treatments stimulate vegetative growth too much, and decrease the sucrose content of the cane seems to be groundless in most cases.

A second experiment was made at Río Piedras on a Vega Alta clay loam comparing ammonium sulfate, ammonium nitrate, liquid ammonium nitrate, and cyanamide. The schedule of treatments and yields of the plant cane are given in table 8. All nitrogen sources used, except liquid ammonim

TABLE 7.—*A comparison of the efficiency of different nitrogen sources on available 96° sugar percent cane at Río Piedras*

[Available 96° sugar as percent cane]

Nitrogen carrier	Treatment in pounds per acre of—			Mean yield of 16 replications in 96° sugar percent cane		
	NH_3	P_2O_5	K_2O	Plant cane, 1944–45	First ratoon, 1945–46	Second ratoon, 1946–47
None	0	50	50	11.61	12.43	12.32
Ammonium sulfate	250	50	50	12.46	12.15	11.78
Ammonium nitrate, one application	250	50	50	12.49	11.91	11.96
Ammonium nitrate, two applications	250	50	50	12.09	12.06	12.05
Uramon	250	50	50	12.26	12.42	12.30
Least significant difference between means at:						
5 percent				0.60	0.54	0.56
1 percent				.80	.72	.74

nitrate produced yields significantly higher than when no nitrogen was used, when all the fertilizers were applied in the liquid form, the yield was only 3 hundredweights higher than when no nitrogen was used. The reason for this may have been rapid leaching of the liquid source before adequate use can be made of it by the plant. Previous experiments on sweet-potatoes using liquid-nitrogen sources also produced low yields (4).

Once again there was no significant difference in yield whether ammonium sulfate or ammonium nitrate was the nitrogen source. This result confirmed the findings in the first experiment at Río Piedras. Cyanamide did not produce significantly greater yields than ammonium sulfate or ammonium nitrate.

The Agro-economic Aspect of the Various Nitrogen Sources

The substitution of ammonium sulfate for ammonium nitrate during the war period brought with it claims by the sugarcane farmers that: 1, The sugarcane crop does not respond as efficiently to the ammonium nitrate applications as it customarily does to those of ammonium sulfate; 2, the high solubility of ammonium nitrate may cause leaching losses of nitrates, and therefore, the supply of nitrogen will be reduced during the long growth period of sugarcane. The results of the experiments to date have shown these claims to be largely unjustifiable.

The results of the Río Piedras experiments performed on a Vega Alta sandy clay in the humid section of the Island indicate that ammonium

Table 8.—*A further comparison of different sources of nitrogen on sugarcane, plant cane, Río Piedras, 1949-50*

Treatment No.	Treatment		Mean yield in available 96° sugar in hundredweights per acre
	Analysis	Pounds per acre	
1	0-6-5	1,200 pounds	75
2	14-6-5	1,200 pounds + 48 pounds NH_3 as ammonium sulfate	104
3	14-6-5	1,200 pounds in liquid form + 48 pounds NH_3 as liquid ammonium nitrate	78
4	18-6-5	1,200 pounds with NH_3 as ammonium sulfate	99
5	18-6-5	1,200 pounds with NH_3 as ammonium nitrate	94
6	18-6-5	Cyanamide	92
Least significant difference between any two means at:			
5 percent			12.7
1 percent			17.0

sulfate and ammonium nitrate are equally good nitrogen sources. The Isabela experiment on a Coto clay in the irrigated northwestern part of the Island revealed a tendency for ammonium sulfate to produce higher yields than the nitrate. This was in the first ratoon and was significant at the 5-percent level. The Guánica experiment revealed no differences attributable to the nitrogen source used. The earlier work showed no differences when ammonium sulfate, sodium nitrate, and cyanamide were compared as nitrogen sources. In general, the nitrogen source used on cane for short periods like the ones used in these tests has no decided effect on yields.

In the selecting of a nitrogen source to be used as a fertilizer material in

Puerto Rico, the following criteria should be considered: a, Nitrogen content; b, form of the nitrogen, whether NH_3, NO_3, or organic; c, cargo space equivalent per unit of nitrogen; d, solubility; e, physical condition for handling, hygroscopicity, plasticity, caking properties; f, residual influence on soil pH; g, cost per unit of nitrogen.

An evaluation was made of the physical and chemical characteristics of the leading nitrogen sources used in Puerto Rico; the results are summarized in table 9. No important differences were revealed in their value as nitrogen fertilizers. This has been shown to be true to date in most of the experiments conducted. Therefore, the choice of a nitrogen source rests mainly upon the economic factors of availability to the purchaser, cost of the material and transportation costs.

The factor of cargo-space equivalent per unit of nitrogen should be evaluated carefully in choosing a nitrogenous fertilizer. Greater quantities

TABLE 9.—*Physical and chemical characteristics of materials used as sources of nitrogen*

Material	NH_3 content (percent)	Nitrogen form	Cargo space equivalent per unit of NH_3	Solubility gm./100 gm. H_2O at 70°F.	Physical condition for handling	Relative value as nitrogen source for sugarcane	Residual influence on soil
Ammonium sulfate	25	NH_4	4.0	75.4	Good	100.0	Acid
Ammonium nitrate	40–42	NH_3, NO_3	2.3–2.5	187.4	Fair	91.2	Do.
Cyanamide	22	CN_2	4.6	[1]	Good	96.0	Alkaline
Uramon	51	$CO(NH_2)_2$	2.0	103.3	do.	95.5	Acid
Sodium nitrate	19	NO_3	5.4	87.6	do.	97.8	Alkaline

[1] Very soluble.

of a nitrogen source with a high cargo-space equivalent must be transported to supply a unit of nitrogen than of one with a low cargo-space equivalent. As all nitrogen sources used in Puerto Rico are imported by ship, the cargo-space equivalent becomes important. Ammonium sulfate, the leading nitrogen source used in the Island, has a cargo-space equivalent of 4, which means that 4 pounds of ammonium sulfate must be shipped to supply 1 pound of nitrogen as NH_3. Ammonium nitrate has an equivalent of 2.4, meaning that only 2.4 pounds are needed to supply 1 pound of nitrogen. Uramon, a urea nitrogen source, has an equivalent of 2, thus 1 pound of it will supply as much nitrogen as 2 pounds of ammonium sulfate.

In choosing a nitrogen source one must consider the physical condition of the nitrogenous material as related to shipping, storage, handling, and incorporation into fertilizer mixtures. Ammonium nitrate which is high in nitrogen and low in cargo-space equivalent offers a good example. Although

its difficult physical handling qualities caused by high hydroscopicity have been improved, its explosiveness when handled in bulk has limited its use in Puerto Rico. The great Texas City disaster and other explosions caused by handling of ammonium nitrate in shipping caused the U. S. Government to impose severe restrictions on its transportation in bulk. The law demands special safety precautions in shipment by boat; and because of the added expense involved, the price of ammonium nitrate in Puerto Rico is now greater than that of ammonium sulfate.

The residual influence of the nitrogen source used on soil pH is not a deciding factor in the choice of nitrogen sources, but it should be given some consideration. Ammonium sulfate, the main nitrogenous material used in the Island, increases the hydrogen-ion concentration of the soil solution when added to the soil. This lowering of the pH can prove beneficial in the southwest parts of the Island where the soil pH is normally above 7. However, in the humid sections, on soils which are already acid, this lowering of the pH by continual use of ammonium sulfate may prove harmful. Lime should be added when fertilizing soils of low pH with ammonium sulfate. The use of cyanamide with its alkaline reaction would prove of value in very acid soils. Calcium cyanamide supplies the soil with 1 pound of calcium carbonate for every pound of cyanamide used. The choice of the proper nitrogen source to be used, as affected by its residual effect, is one which must be made in the light of existing soil pH, the soil type, the crop, and the quantity of nitrogenous material to be used.

The status of the nitrogen sources used in Puerto Rico should not be regarded as static. The question must be weighed in the light of new agricultural chemical discoveries and further field experimentation. Fortunately, the Agricultural Experiment Station has adopted a research program which constantly tests both new and promising as well as existing nitrogen sources in the varied soil and climatic conditions of Puerto Rico.

Summary

1. A survey of the literature of earlier fertilizer trials in Puerto Rico in which the efficiency of ammonium sulfate, sodium nitrate, tankage, and calcium cyanamide were compared revealed that there was no significant difference in the yield response of sugarcane to these nitrogen carriers.

2. Experiments were conducted in which ammonium sulfate and ammonium nitrate were compared as nitrogen sources for sugarcane. The results at Río Piedras and Guánica showed no significant differences in yield of cane or sugar regardless of which was used. At Isabela there was a better response to ammonium sulfate than to ammonium nitrate in the first ratoon, but it was significant only at the 5-percent point.

3. Uramon and cyanamide when tested along with the ammonium sulfate

and nitrate experiments at Río Piedras and Isabela, produced no significant responses as compared with the other nitrogen sources. At Río Piedras liquid ammonium nitrate produced the lowest yield of any nitrogen source used.

4. Ammonium sulfate is the chief nitrogen source used in Puerto Rico. Its use is chiefly dictated by economic and manufacturing conditions. Ammonium nitrate, which is cheaper per unit of nitrogen, cannot be used at present because of extremely high transportation costs based on its explosiveness.

5. A discussion of the agro-economic aspect of nitrogen sources is presented.

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THE HANDLING OF SUGARCANE TRASH

I. YIELD AND ECONOMIC CONSIDERATIONS

Pablo Landrau, Jr. and George Samuels[1]

Introduction

The proper handling of trash in sugarcane fields is an item of great importance to Puerto Rican sugarcane growers because of its direct bearing on the cost of production, yield of cane, and such various aspects of soil conservation as erosion, infiltration, organic-matter content, and structure. The handling of trash is an essential part of the agronomic practices used with sugarcane. Its proper management can mean greater profits to the sugarcane grower not only because of savings in labor costs but also from increases in yields.

Sugarcane trash is the material left on the surface of the ground after harvesting sugarcane, and consists of all the leaves and the upper immature part of the stalk. For 1949, when 10,998,026 tons of cane were ground in Puerto Rico with an average acre yield of 31.2 tons of cane per acre (4),[2] this represented 2,749,506 tons of dry sugarcane trash.[3] This trash contained 93 pounds of combined nitrogen per acre. If handled properly this trash becomes an asset; if misused it can become a liability to the sugarcane grower.

The utilization of the trash presents practical difficulties, and many sugarcane planters burn it. The trash is very bulky and difficult to plow under or to plow through in the cultivation of the crop. If it is buried or plowed under deeply, the decomposition may be too slow and effective use of soil nitrogen is hindered. Should the trash remain undecomposed, there is also the possibility that it may serve to protect the resting stage of insects injurious to the cane, and that under conditions of excessive moisture and low temperature its presence may increase the infection of the cane by facultative parasitic fungi in the soil.

Bonazzi (1), Bonnet (2), and Sturgis (6) have reported that the incorporation of sugarcane trash into the soil increased the total soil nitrogen as it decomposed. They also found the addition of inorganic nitrogen to the trash in the soil hastened its decomposition.

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[2] Numerals in parentheses refer to Literature Cited, p. 245.

[3] Calculated from a cane-trash ratio of 4:1 as estimated by Hardy (3).

Procedures

In order to study and determine the effects of different ways of handling the trash on yields of sugarcane, experiments were established at Río Piedras and at Isabela. The treatments and other field information are given in table 1.

The procedures for the handling of the trash for each treatment were as follows:

Trash burned: The trash was spread evenly over the plot and then burned.

Trash aligned: The trash was aligned in alternate banks or rows.

Trash buried: A furrow was made about 1 foot deep between rows; the trash was placed in the furrow and covered with soil.

No manipulation: The trash was left untouched as found in the field after harvesting the cane.

Table 1.—*Treatments and field information of trash experiment*

Item	Río Piedras experiment	Isabela experiment
Treatment A	Trash burned	Trash aligned
Treatment B	Trash buried	Trash aligned and plowing
Treatment C	Trash aligned	Nonmanipulation of trash
Treatment D	—	Trash burned
Planting date	June 21, 1944	February 10, 1946
Soil type	Vega Alta silty clay	Coto clay
Replication	20	9
Sugarcane variety	P.O.J. 2878	P.R. 905
Planting rate	12,000 3-eye seed pieces per acre	10,200 3-eye seed pieces per acre

Trash aligned and plowed: The trash was aligned in alternate banks or rows and a shallow furrow was opened in the clean banks.

The planting, cultivation, and fertilizer application were carried out in the normal manner used by the cane growers in their respective regions.

Experimental Results

Río Piedras experiment

The results for a plant cane and six ratoon crops are presented in table 2.

The results for the plant cane were utilized as a uniformity test of the field because the various treatments were not applied until after the harvest of the plant cane. The results showed no significant differences between treatments or plots which indicated that the experimental site selected had no differences in fertility which might tend to obscure the results of the various treatments. This uniformity in fertility was of importance in that the

differences obtained by subsequent treatments could be attributed to the treatment effect and not to soil variations.

No significant differences in the yield of available 96° sugar in hundredweights per acre were obtained for the first four ratoon crops. Significant differences in yields, however, were obtained in the fifth and sixth ratoons. For the fifth ratoon the aligned-trash treatment was significantly better at the 5-percent level over the burned-and buried-trash treatments. This increased to a significance at the 1-percent level for the sixth ratoon. There were no significant differences between the burned- and buried-trash treatments.

The results of a combined analysis of the mean yield of the sixth ratoon crops show no significant differences between the treatments in yields of sugar per acre. It is important, however, to give attention to the fifth and

TABLE 2.—*Mean yields of available 96° sugar of a plant cane and 6 ratoon crops at Rio Piedras*

Treatment letter	Treatments	Mean available 96° sugar per acre for—							
		Plant cane	First ratoon	Second ratoon	Third ratoon	Fourth ratoon	Fifth ratoon	Sixth ratoon	Mean yield of 6 ratoon crops
		Cwts.	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*	*Cwts.*
A	Trash burned	55	106	127	109	107	114	91	109
B	Trash buried	54	107	125	108	109	115	96	110
C	Trash aligned	54	106	127	105	105	122	99	111
Least significant difference at:									
	1-percent level	5.35	7.98	11.07	9.18	8.60	8.64	7.27	6.11
	5-percent level	3.99	5.96	8.27	6.86	6.43	6.46	5.44	4.56

sixth ratoon crops. The effect of the treatments after 5 years of continuous cultivation began to produce significant differences in yields. The first few years these differences are not observed and the results tended to give a false picture. With increases in time of cultivation, the small differences accumulated and made themselves known.

Field observations made during the early stages of growth of this fifth and sixth ratoon crops showed that the burning and burying of the trash retarded the growth of the cane as compared with the aligned-trash treatment. This growth delay may be caused by the intense heat of burning or the destruction of roots in burying. At later stages of growth no differences in growth height was observed. However, plots under the burned- and buried-trash treatments were more quickly overgrown with weeds than those under the aligned-trash treatment. This means that cultivation costs

will be higher in the burned- and buried-trash plots than in those where the trash was aligned.

ISABELA EXPERIMENT

The results of two plant-cane and two ratoon crops are given in table 3. There were no significant differences in yield attributable to any treatments used. In this experiment no manipulation, which of course had the lowest labor cost, gave yields equal to the other treatments whose labor costs were higher. Aligning the trash showed no superiority over the other treatments. It must be remembered, however, that significant differences in yield from treatments were not obtained until the fifth ratoon at Río Piedras.

TABLE 3.—*The mean yield of cane and sugar for 4 crops at the Isabela Substation*

Treatment	Treatment	Mean yield of cane per acre from plant cane, 1946–47	Mean yield of available 96° sugar per acre from—		
			First ratoon 1947–48	Second ratoon 1948–49	New planting 1949–50
		Tons	*Hundredweights*	*Hundredweights*	*Hundredweights*
A	Trash aligned	40.1	98	83	101
B	Trash aligned and plowing	39.7	94	75	101
C	No manipulation	40.9	104	82	98
D	Trash burned	38.1	96	70	107
Least significant difference at:					
	1-percent level	6.6	17.91	41.09	17.06
	5-percent level	4.9	13.20	30.29	12.59

The results obtained indicate that burning or burying the trash is detrimental to sugarcane production when continued over a period of years. However, where burning is necessary, and where sugarcane trash must be eliminated for easier harvesting, it is safe to follow this practice for 1 or 2 years. In general, this practice should be avoided by sugarcane growers because the costs of cultivation increase because of rapid weed infestation. It would be of greater benefit to the farmers to leave the trash untouched in the field; however, this practice can be followed only in areas where irrigation is not normally used; where irrigation is practiced, it has to be avoided because the presence of the trash hinders irrigation. As the cost of sugarcane production is increasing every year, it is recommended that the trash be left in the field untouched. The cost of cultivation is decreased greatly by following this method.

Discussion

The handling of sugarcane trash should not be considered merely for its effect on the yield of sugarcane. Consideration must also be given to the effects of the various methods of trash disposal on the costs of cane cultivation. A method that gives high yields may cancel this benefit by its higher labor costs. An important consideration also is the long-range effect of treatments on the soil in relation to erosion, water infiltration, drainage, aeration, and organic-matter content. Although the soil appears to assume a passive role, it may become quite an active factor if the methods of trash disposal are deleterious to it.

From an economic standpoint, no manipulation of the trash is, of course, the cheapest. The low cost of cultivation by this method arises not only because no labor is used to handle the trash after harvesting, but also because the carpet of trash deters weed growth and lowers weeding costs. It also offers excellent protection against soil erosion. The carpet of trash prevents washing away of the soil by heavy rains just after harvesting the cane. In an experiment at Mayagüez (5) 14,000 pounds of soil were washed away where trash was burned, as compared with only 1,200 pounds during the same time where the trash was undisturbed. Bonazzi (1) reported in Cuba that leaving the trash on the ground (no manipulation) formed an effective mulch which retained soil moisture during dry periods. Covering the soil with trash fostered the accumulation of considerable quantities of nitrogen under the optimum moisture conditions thus provided. When the trash was incorporated into the soil by Bonazzi lower available nitrate nitrogen resulted than when the trash was undisturbed on the surface. Thus, no manipulation of trash has another advantage in its control of soil moisture and available soil nitrates, but it has the disadvantage that it tends to smother the new ratoon, and replanting is necessary with varieties which ratoon vigorously. Another disadvantage is that it reduces the efficiency of the drainage ditches by clogging them. On level soils or areas of poor drainage in the humid part of Puerto Rico this method may give lower yields because the excess moisture is not carried away by the ditches. Of course, this method is not much used in irrigated areas where the ditches must be kept free of the trash for efficient irrigation.

Burying or burning the trash offers no increase in yields, and over a period of years, gives lower yields than the normal practice of aligning it. Burying the trash is not cheaper than aligning. Burning the trash is cheaper than aligning or burying, but, on continued use, lowers yields, increases soil erosion, and necessitates higher weeding costs.

From the information obtained in these experiments, supplemented with field observations, the alignment of trash is now the best general practice for Puerto Rico from a standpoint of yields, labor costs, and soil erosion

control. In areas where irrigation is not used or drainage is not a serious problem no manipulation of the trash is a more economical practice, but this method should be limited to certain areas of the Island only.

Summary

1. Experiments on handling of sugarcane trash were established at Río Piedras and Isabela, with treatments consisting of burning, burying, and aligning the trash.

2. In Río Piedras there was no difference in sugarcane yields that could be attributed to any of the treatments until the fifth and six ratoon. Here significant differences in yields were obtained from aligning trash accompanied with burning or burying it.

3. At Isabela, no differences in yields were obtained for four crops of a plant cane, two ratoons, and a plant cane. No manipulation of the trash gave yields equal to aligning, burning, or burying it.

4. Field observations indicated that weeding costs were greater when the trash was burned or buried, as compared with aligning or with no manipulation of the trash.

5. The various practices and their value from the standpoint of yields, costs of cultivation, and soil erosion value are discussed. The general recommendation from present data for Puerto Rico is that the sugarcane trash should be aligned.

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THE HANDLING OF SUGARCANE TRASH

II. EFFECTS OF VARIOUS PRACTICES ON SOIL PROPERTIES

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Introduction

The sugarcane crop leaves a large residue of plant material after harvesting which consists mostly of green tops, roots, and dry trash. The green tops, as a rule, are used as fodder for farm livestock. The roots remain in the soil and contribute to the maintenance of the organic-matter level. The dry trash, consisting of all the leaf blades and sheaths, is left on the field where it is either burned, buried, aligned in alternate banks, or left undisturbed as a mulch over the surface of the soil.

Hardy and Evans (4)[2] estimated that for every 4 tons of green millable cane a ton of trash was produced. Bonnet, et al (2) report a mean cane-trash ratio of 5:1 from a plant crop and three ratoons of POJ 2878 raised at Mayaguez from 1945 to 1948. For the Puerto Rican 1949 crop where nearly 11 million tons of cane were harvested from 359,743 acres, this amounts to returning almost 8 tons of dry trash to the acre, taking Hardy's ratio (9, 11) as a basis.

Bonnet, et al compared the effect of leaving the trash as mulch or burning it, for four crops of sugarcane (1944–1948) grown in a lateritic soil with a 40-percent slope. No significant differences in yields were found between treatments. However, highly significant differences were found between soil losses, the unmulched plots loosing about 11 times as much soil as the mulched ones (2). Landrau and Samuels (6) have reported previously on yields and economic considerations as affected by different methods of handling trash in experimental fields at Isabela and Río Piedras.

At Isabela no differences in yields were observed for four crops of cane (1946–1950) whether the trash was aligned, burned, buried, or left as a mulch over the surface. At Río Piedras the effects of burning, burying, or aligning the trash in alternate rows were compared and there were no significant differences in the yields per acre of available 96° sugar for the first four ratoon crops. However, the plots where the trash had been aligned gave significantly higher yields of sugar in the fifth and sixth ratoons than those where it was either burned or buried. The plots where the trash was burned

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[2] Numbers in parentheses refer to Literature Cited, p. 254.

tended to produce yields lower than those where it was buried, but the differences were not significant.

This paper reports on soil conditions at the experimental field at Río Piedras where treatment differentials have been established for the last 6 years, 1945–1951 (6).

Materials and Methods

The trash-handling experimental field at Río Piedras was established in 1945 at the Solís farm in an area previously mapped as Vega Alta silty clay, a rather extensive sugarcane soil of the humid area (10). A soil profile to a depth of 72 inches obtained at the middle of the experimental field on April 2, 1951, by using a Kelley soil-sampling machine (5), revealed a very dark grayish-brown (10 YR 4/2) surface of about 11 inches in depth with a moderately developed angular structure. The 12–29-inch layer was yellowish red (5 YR 5/8) with considerable red mottling and a moderately developed subangular structure. The 30–72-inch layer was a yellowish brown (10 YR 5/8) silty clay loam, with red and gray mottling.

The procedures for the handling of the trash in each treatment were as follows:

Trash burned: The trash was spread evenly over the plot and burned.

Trash aligned: The trash was aligned in alternate banks.

Trash buried: A furrow was made about 1 foot deep between rows; the trash was placed in the furrow and covered with soil.

The treatments were repeated every year after harvest. Each treatment was replicated 20 times. The plots were 150 feet long by 20 feet wide and the cane rows were 4 feet apart. The plots were arranged following a randomized block lay-out. The variety of cane used was POJ 2878. The field as a whole received an application of 1,200 pounds of a 15–3–10 fertilizer every year. After the sixth ratoon was harvested, infiltration tests were run in the field and samples taken from each plot for laboratory analysis.

Bulk composite samples were taken from the topmost 6 or 8 inches of soil. Each composite consisted of 10 samples. Undisturbed cores, 3 inches in diameter and 3 inches in length, were also taken at two depths, 0–3 inches and 4–7 inches, by making use of a Bradfield soil sampler. The buffer-compartment method outlined by Nelson and Muckenhirn was used (7) to determine the infiltration rate. Iron rings 9, 18, and 27 inches in diameter were jacked into the soil. A $\frac{1}{4}$-inch head of water was maintained in the center ring by means of a self-dispensing calibrated 2,000 c.c. burette. The same hydraulic head was maintained in the outer compartments to minimize lateral movement of water from the inner ring where measurements were taken by the hour. The tests were run for 8 consecutive hours.

Permeability measurements were made in undisturbed soil cores by recording the rate at which water moved through a column of saturated soil at a known head. Special equipment described by Smith, Furhiman, and Silva (12) was used in making these measurements. Quick drainage was determined by putting the saturated core in a Büchner funnel, setting a 60 cm. tension, and measuring the water drained out at the end of 15 minutes. The water removed and retained at pF 1.78 was measured by bringing the soil core to equilibrium with a 60-cm. tension and determining the variation in weight of the core. The maximum saturation was calculated from the above data.

The soil core was finally dried in the oven at 110°C. As the samples used had a definite known volume, the bulk density of the soil was calculated by dividing the net dry weight of soil by its volume. The pore space was then calculated by assuming a specific gravity of 2.65. The air porosity,

TABLE 1.—*Mean pH, nitrogen, organic matter, and C/N ratio of soils from the trash-handling experimental field at Río Piedras*

Treatment	Treatment	pH	Nitrogen	Organic matter	C/N ratio
			Percent	*Percent*	
A	Trash burned	5.08	0.145	1.425	5.7
B	Trash buried	4.92	.149	1.825[2]	7.8[1]
C	Trash aligned	5.03	.144	1.700[2]	7.0
L.S.D. at the 5-percent level		.179	.018	.223	1.70
L.S.D. at the 1-percent level		.239	.024	.298	2.27

[1] Significant at the 5-percent level.
[2] Significant at the 1-percent level.

as used in this paper, is the difference between the theoretical pore space and the volume of water retained at pF 1.78.

The pH was determined electrometrically by means of a Macbeth pH meter. Total nitrogen was determined by using the standard Kjaldahl method and the organic matter by the simple colorimetric Schollenberger technique. The carbon-nitrogen ratio was subsequently calculated from the above data.

RESULTS AND DISCUSSION

The results of the chemical analysis of the soils taken from the Río Piedras trash handling experimental field are shown in table 1. The general pH values ranged between 4.5 and 6.2 with a mean value of pH 5.0 for soils under all treatments combined. There were no significant differences between the means of the treatments. The mean nitrogen content of soils

under all combined treatments was 0.146 percent. There were no significant differences between the mean nitrogen content of soils from the plots, whether the trash was burned, buried, or aligned. However, soil from the plots where the trash was either buried or aligned had a much higher organic-matter content than that from those where it was burned. After 6 years of establishing the treatment differentials, the accumulated differences were clearly marked. The results were highly significant.

The plots where the trash was aligned or buried had been receiving not less than 8 tons of trash to the acre after each harvest, which amounts to 48 tons during the cycle of one plant crop and five ratoons. The accumulation of organic matter in the soil is a rather slow process. Regarding the weight of the acre-furrow-slice as 2 million pounds, the organic residues added during the crop cycle should amount to 4.8 percent. However, it must be considered that a large proportion of the organic matter added is decomposed by the micro-organisms of the soil, releasing essential nutrients for plant growth.

Furthermore, the sugarcane trash has a wide C/N ratio of about 40:1 (1, 8). By the time the residues become an integral part of the soil, this ratio is usually narrowed to 10:1. Thus the 48 tons of organic material become 12 tons of organic matter with a C/N ratio of 10:1, which is equivalent to 1.2 percent of organic matter in the plow layer. This decomposition of the trash is rather rapid under the climatic conditions of the Tropics which greatly hasten such processes. Therefore, in spite of the seemingly large additions of plant residues to the plots where the trash was buried and aligned, as compared with those where it was burned, the increases in organic-matter content in soils from the first two as compared with the last were only 0.4 percent for burying and 0.3 percent for aligning. There were no significant differences between the effects of burying and aligning the trash.

The mean soil C/N ratios were 5.7, 7.8, and 7.0 for the burned-, buried-, and aligned-trash treatments respectively. The difference between burying and the burning is significant. In general, the ratio was narrower in the plots where the trash was burned. In the other plots which received large quantities of carbonaceous plant material for 6 consecutive years, the ratio was a little wider. However, all these ratios considered together were less than 10:1, which indicates that the trash decomposed quickly. No wide C/N ratios indicative of slow decomposition were observed. The field as a whole received a yearly application of 1,200 pounds of 15–3–10 fertilizer to the acre, which insured an adequate supply of nitrogen for both micro-organisms and plants during the early critical stages of crop growth.

Table 2 gives the mean infiltration rate of the soil determined for each

of 8 hours on plots where the sugarcane trash was differently handled for the past 6 years.

In general, the soil infiltration rate was slower in the plots where the trash was burned than in those where it was either buried or aligned. Burying the trash disturbed these plots mechanically every year in the making of a furrow between cane rows which promoted a higher rate of infiltration. This high rate of infiltration is especially beneficial in Puerto Rico where heavy rainfalls of short duration are not uncommon. Soils with a lower infiltration rate cannot absorb as much water and most of the rain is lost as runoff. Whether significant differences in infiltration rates will be obtained with larger accumulations of organic matter in the soil remains to be seen.

In addition to the infiltration rates determined under field conditions, a number of undisturbed soil cores was taken for soil-moisture studies

TABLE 2.—*Rate of infiltration of soils where sugarcane trash was burned, buried, or aligned for 6 consecutive years*

Treatment	Treatment	Infiltration rate in inches of water per hour at hour indicated							
		1	2	3	4	5	6	7	8
A	Trash burned	7.54	2.76	2.00	1.76	1.98	1.55	1.35	1.40
B	Trash buried	14.77	7.06	4.04	3.56	3.17	2.50	2.96	2.38
C	Trash aligned	9.93	4.36	3.10	3.05	2.78	2.47	2.34	2.00
Minimum required for significance at the eighth hour									3.11

under laboratory conditions. The results of the permeability tests and other soil-moisture measurements performed are reported in table 3.

In general, there were no outstanding or significant differences in the moisture characteristics of the soils undergoing the various trash-handling treatments. Some trends, however, should be pointed out. Perhaps they will become significant when the anticipated larger differences in organic-matter levels occur in later years as a result of some methods of handling the trash. The movement of water as indicated by permeability measurements appeared to be slower in the soil of plots where the trash was burned than in the others. Soil from plots where the trash was aligned in alternate rows seemed to have a higher moisture content at maximum saturation than that from plots which underwent either one of the other treatments. More water was removed from soil cores that reached equilibrium with a 60-cm. tension when they came from the plots where the trash was burned than when they came from plots where it was either buried or aligned. The last column of table 3 indicates that the upper layer of soil from the

plots where the trash was aligned retained more water at low tensions than that from plots where the trash was buried or burned. Soil from the plots where the trash was buried retained the least volume of water at pF 1.78. In all probability this water was readily available, the plants being able to remove it quickly until tensions in the vicinity of the permanent wilting percentage (pF 4.2) were reached.

Although the recorded differences were not significant, it does appear that, when carried out over a period of years, trash burning is not a beneficial practice, at least insofar as total water retention is concerned; perhaps the total available water is also reduced. This may have a bearing upon cane and sugar yields. Aligning the trash has been previously reported to produce significantly higher sugar yields than either of the other two

TABLE 3.—*Permeability and other soil-moisture data gathered from soil cores collected from the trash-handling experimental field at Río Piedras*

Treatment	Treatment	Sampling depth	Permeability	Water drained at 60 cms in 15 minutes	Maximum saturation	Water removed at pF 1.78	Water retained at pF 1.78
		Inches	*In./hour*	*Inches*	*Percent*	*Percent*	*Percent*
A	Trash burned	0–3	0.51	2.65	50.92	5.42	44.97
		4–7	1.60	.77	51.80	2.30	49.40
B	Trash buried	0–3	.44	1.38	49.90	3.58	46.15
		4–7	4.00	1.15	50.47	2.65	47.80
C	Trash aligned	0–3	.80	2.25	54.70	4.70	50.00
		4–7	6.67	.98	52.42	2.68	49.70
Minimum required for significance		0–3	.53	1.51	3.42	2.01	4.39
		4–7	9.39	.48	1.72	1.12	1.67

treatments at the fifth and sixth ratoon crops. No significant differences were observed in the earlier four crops in the cycle (6). The accumulation of organic matter in the soil with the consequent, although slow, change in its physical nature, may serve to explain yield differences.

Table 4 presents data on bulk density, total porosity, and air porosity of soils taken from the variously treated plots. The bulk-density values range from mean values of 1.26 gm./c.c. for soil from the plots where the trash was burned or buried to 1.19 gm./c.c. for the soil under the aligned-trash treatment. The mean porosity value for soil from all plots was 52.54 percent by volume, with deviations of only 2.54 percent above or below. The air porosity was highest for soil from plots where the trash was burned, next highest from those where it was buried, and lowest from those where

it was aligned. The air porosity was in inverse relationship to the water porosity (water retained at pF 1.78) the total pore space being more or less constant.

The incorporation of large amounts of organic residues in a continuous, steady way for a number of years probably produces a better state of aggregation and consequently the formation of a larger proportion of microaggregates capable of holding considerable quantities of water at relatively low tensions. This fact has been substantiated by Browning and Milan (3) and others who found significant increases in aggregation with each unit increase in organic matter. The larger the air porosity, the larger the proportion of coarse pores, and therefore relatively less water is available for crop growth.

TABLE 4.—*Bulk density, pore space, and air capacity of soils from the sugarcane trash-handling experimental field at Río Piedras*

Treatment	Treatment	Sampling depth	Bulk density	Pore space	Air porosity (pore space-water retained at pF 1.78)
		Inches	*Gm./c.c.*	*Percent*	*Percent*
A	Trash burned	0–3	1.26	52.45	7.48
		4–7	1.28	51.47	2.07
B	Trash buried	0–3	1.26	52.25	6.10
		4–7	1.28	51.68	3.88
C	Trash aligned	0–3	1.19	55.12	5.12
		4–7	1.26	52.63	2.93
Minimum required for significance		0–3	.097	3.98	—
		4–7	.048	2.10	—

SUMMARY

Data are presented here for various soil characteristics on plots where the sugarcane trash had been either burned, buried, or aligned in alternate rows for 6 consecutive years in a plant and 6-ratoon crop cycle. The experiment was established in a Vega Alta silty clay, a rather extensive sugarcane soil of the humid area. After the sixth ratoon crop was harvested, infiltration tests were run in the field and bulk and core samples taken for laboratory analysis. No significant differences were observed between the mean pH and total nitrogen values of soil under the various treatments. The mean organic-matter content of soil from plots where the trash was burned was significantly lower, at the 1-percent level, than that of soil from plots where it was buried or aligned. The C/N ratio was narrow in all cases, but lower under the burned-trash treatment.

The mean infiltration rates at the eighth-hour run were 1.40, 2.00, and 2.38 inches per hour for soils that underwent the burned-, aligned-, and buried-trash treatments, respectively, but the differences were not significant. No significant differences were observed between the means of the various physical measurements performed, namely, permeability, quick drainage, maximum saturation, water removed and retained at pF 1.78, bulk density, total porosity, and air porosity. Some trends observed may become significant with continuous accumulation of organic matter in soils undergoing the buried- and aligned-trash treatments. For instance, the permeability of soils from plots where the trash was burned tended to be lowest, and the upper layer of soil from plots where the trash was aligned seemed to retain more water at low tensions than the upper layer of soil from plots treated otherwise.

Resumen

En este estudio se presentan datos sobre varias propiedades del suelo en aquellas parcelas donde la paja de la caña de azúcar se quemó, se enterró, o se alineó en hileras alternadas, por seis años consecutivos. El campo donde se estableció el experimento está formado por una arcilla limosa de la serie Vega Alta. Este suelo, propio para la caña, se encuentra bastante extendido por toda la zona húmeda de Puerto Rico.

Después de la cosecha del sexto retoño, se hicieron pruebas de infiltración en el campo y se tomaron muestras, incluyendo columnas de suelo en su estado natural, para analizarlas en el laboratorio. No se observaron diferencias significativas entre los valores pH y el contenido de nitrógeno total promedio de cada tratamiento. El contenido promedio de la materia orgánica de las parcelas, donde se quemó la paja de caña, resultó ser significativamente más bajo (al 1 porciento) que el de aquellas parcelas donde se enterró y se alineó la paja en hileras alternadas. La razón C/N fué baja en todos los tratamientos, y menor en las parcelas donde se quemó la paja. Las pruebas de infiltración en el perfil, dieron, como promedio, 1.40, 2.00, y 2.38 pulgadas por hora a la octava hora, en las parcelas donde la paja se quemó, se alineó y se enterró, respectivamente. Sin embargo, las diferencias no fueron estadísticamente significativas.

No se observaron diferencias significativas entre los promedios de las varias propiedades físicas medidas, a saber: permeabilidad, agua removida en 15 minutos a una tensión de 60 centímetros, saturación máxima, agua removida y retenida a pF 1.78, peso por volumen, porosidad total y proporción de poros gruesos. No obstante, se observaron algunas tendencias que podrían resultar significativas si se continuara la acumulación de la materia orgánica, tal y como occurre en las parcelas donde la paja de caña se entierra y se alínea. Por ejemplo, se observó que la permeabilidad aparentemente fué más lenta en las parcelas donde se quemó la paja. El suelo

de las parcelas, donde se alineó la paja pareció capaz de retener más humedad en su capa superior a tensiones bajas, que el de las parcelas que recibieron otros tratamientos.

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THE BENEFICIAL EFFECT OF FILTER PRESS CAKE ON PINEAPPLE GROWTH, DEVELOPMENT, AND PRODUCTION

I. EFFECT ON THE PLANT CROP

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Introduction

Pineapple is the third most important agricultural export crop in Puerto Rico, being preceded only by sugarcane and tobacco, in that order. During the fiscal year 1948–49, the total value of fresh pineapples exported amounted to $1,164,039 while that of the canned fruit and juice exports amounted to $2,550,370, making a grand total of $3,714,409 (1).[2]

Because pineapple production has great potentialities in the years to come there is incentive to exert effort towards the solution of the most urgent physiological and agronomic problems of pineapple production in the Island.

One of the problems that received special attention in the past by Hopkins and his coworkers in Puerto Rico (6) was that of the minor elements iron and manganese as bearing on pineapple growth. Under greenhouse conditions he demonstrated the importance of the interrelationship of iron and manganese in the metabolism of pineapples. In preliminary pot-test work with beans grown in soil obtained from a typical pineapple-growing area, he prevented severe chlorosis of the first trifoliate leaves characteristic of manganese toxicity by adding calcium carbonate to raise the pH of the soil to 6.2. This led him to suggest that manganese toxicity chlorosis of pineapples could be prevented by raising the pH of the soil with calcium carbonate. From this, it may be inferred that a great proportion of the soil manganese is unavailable or insoluble to such an extent that the available iron in the soil is not antagonized by the remaining available manganese, and thus pineapple chlorosis does not occur.

As a result of Hopkins' findings, and following his suggestions with respect to the possible usefulness of calcium carbonate in the control of

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[2] Numbers in parentheses refer to Literature Cited, p. 280.

excessive soluble manganese in the soil, two pineapple experiments were established in the fall of 1947. In addition to the use of calcium carbonate as one of the treatments the addition of organic matter in the form of filter press cake was also tested. Filter press cake is a byproduct of the sugar mills of Puerto Rico. The purpose of this study was to develop remedial treatments which would counteract the adverse effects of iron-manganese imbalance in the soil upon the growth, development, and production of pineapples.

Materials and Methods

CULTURAL TECHNIQUE

The first of the two pineapple experiments was started on November 25, 1947. Pineapple slips of the Red Spanish variety selected for uniformity in size and weight were planted in the open site, in ebonol-painted half-drums in soil obtained from a typical pineapple area in Palo Blanco, Arecibo. This lateritic soil is classified as Bayamón silty clay (8). It has been in continuous pineapple cultivation for about 20 years. The average pH of this soil as determined with a glass electrode was 4.49, a relatively high acidity.

The second pineapple experiment was started also on November 25, 1947. The same variety of pineapple slips were used but these were planted in Fajardo clay soil, which is an acid lateritic soil derived from ashy shales (4). This soil was obtained from the Experiment Station Farm near Río Piedras. The average pH of this soil as determined with the glass electrode was 4.48.

Both pineapple experiments were established following a randomized block arrangement. There were 5 treatments, each treatment was replicated 10 times, making a total of 50 plants in each experiment. A general view of the experiments is presented in figure 1.

The treatments tried in both experiments were as follows: A, Soil treated with calcium carbonate to raise its pH to 6.2; B, soil treated with calcium carbonate to raise its pH to 7.2; C, filter press cake mixed with the soil; D, ferrous sulfate sprays applied to the plants; and E, control or untreated plants and soil. The lime-requirement determinations to bring the soil pH to the expected values were made according to the method of Riera (9). Filter press cake was added and mixed with the top 6 inches of soil in amounts equivalent to 10 percent of the weight of the soil used per drum. The ferrous sulfate spray was prepared by dissolving commercial ferrous sulfate in tap water at the rate of 25 lbs. of the salt in 100 gallons of water, equivalent to a 3-percent solution of the salt. Only one spray treatment was given to the plants approximately 4 months after planting.

All pineapple plants undergoing the various treatments received commercial pineapple fertilizer, formula 12[3]–6–10, at the rate of $1\frac{1}{2}$ tons per acre. Four applications of this fertilizer were made during the vegetative cycle of the plants, a method ordinarily used in commercial pineapple plantations.

Seven months after planting, on June 30, 1948, leaf samples were taken from plants representatives of each treatment, and chemical determinations were made of total and soluble iron and manganese. The active or largest leaf of each plant was selected for this purpose (12). The leaves

FIG. 1.—General view of pineapple experiments established in Bayamón silty clay from Palo Blanco, Arecibo and Fajardo clay from Experiment Station Farm, Río Piedras.

from the plants under each treatment were cut with a stainless steel knife, the midsection being utilized for the chemical analyses. These were first washed with distilled water as completely as possible and then rinsed in fresh distilled water. All the midsections of leaves corresponding to a treatment were put together and sectioned into small pieces so that there was a composite sample of leaf tissue for each treatment. The composite sample was well mixed and divided into two similar portions, one of which was dried in an oven at 65°C. for 48 hours to be used for determina-

[3] As ammonia (NH_3)

tions of total iron and manganese. The second portion of the leaf-tissue was frozen quickly in a refrigerator at approximately minus 20°C. until ready for analysis.

To induce flowering, the plants from both experiments were treated with acetylene on November 30, 1948, approximately 1 year after being planted. This consisted in applying to the crown of the plant about 25–30 ml. of a solution made by dissolving 2 ounces of calcium carbide in 5 gallons of water in a closed container.

ANALYTICAL METHODS

Aliquot portions of the finely ground tissue for the determination of total iron and manganese were gradually digested with 2-ml. concentrated H_2SO_4 and approximately 2-ml. H_2O_2 until the solution was completely clear. This was made to volume in a 50-ml. volumetric flask and aliquots of this solution were used for the determination of total iron and manganese. Iron was determined according to the Saywell and Cunningham orthophenanthroline method (10) while manganese was determined by the periodate method as described by Peech (7). A Coleman spectrophotometer, model 14, with filter PC-4 at a wave length of 490 mu and with filter PC-4 at a wavelength of 525 mu was used for the determinations of iron and manganese, respectively.

For determinations of soluble iron and manganese the leaf samples which had been frozen immediately after harvest were thawed, wrapped in a piece of muslin of suitable size, and subjected to a pressure of 2,750 pounds per square inch in a Carver press for three consecutive periods totaling 4 minutes. Approximately 30 ml. of distilled water were used with each sample at each period to aid in the removal of the cell sap. The extracted plant juices and washings were filtered through a No. 5 Whatman filter paper, and the residue was added to the pressed sample which, after being removed from the muslin, was covered and dried in an oven at 70°C. for 48 hours. The filter paper was ashed and added to the pressed sample. The material was then ground in a semimicro Willey mill to a fine powder as were the samples used for the determination of total iron and manganese. Aliquots of the ground tissue were used for iron and manganese determinations.

The soluble iron and manganese content of the juice or cell sap was obtained by subtracting the iron and manganese found in an extracted sample from the quantities obtained by analysis of an unextracted sample. In other words, the iron and manganese that remained in the press cake after extraction were regarded as the insoluble or unavailable portions of these elements in the plant tissue analyzed.

HARVESTING PROCEDURES

The pineapple fruits from the plant, or first crop, of both experiments were harvested during May and June of 1949. In addition to yield of fruits number of slips and number of suckers were considered as criteria in obtaining the results to be discussed in this paper. Slips are the axillary offshoots which arise from the buds found nearest to the base of the fruits in the fruiting stalk of the plants and which are used for commercial plantings. Suckers are the axillary offshoots which arise from the buds found at the base of the stem of the plant and which give rise to the ratoon or second crop.

The results of each experiment will be considered separately, but they will be considered jointly in the discussion.

Experiment on Soil Type Bayamon Silty Clay from Arecibo

EXPERIMENTAL RESULTS AND STATISTICAL INTERPRETATION

Effect of Treatments on Plant Growth

During the vegetative cycle a striking difference was observed in the growth made by plants which received filter press cake as a soil remedial treatment and those subjected to other treatments (figure 2). These plants made considerably more vegetative growth, were more vigorous, were greener in color, and practically all of them had produced suckers before the application of calcium carbide to induce flowering. The stems of these filter-press-cake-treated plants were stouter and the leaves were wider than those of plants undergoing other treatments. The filter-press-cake-treated plants were greener in color than the plants which received the ferrous sulfate spray, while the lime-treated plants were light green. In fact, it was very easy to select among all plants those that grew in soil which was treated with filter press cake since they were the tallest, stockiest, and darkest green among the plants, as can be observed in figure 1. These same plants developed thicker flower stalks than the others. Judging from the size of these plants and the thickness of their flower stalks it was logical to assume that their fruit yields would be greater than those of plants undergoing other treatments; this was found to be true on harvesting.

Effect of Treatments on Yield of Fruits

The data obtained with respect to mean weight of fruits under each treatment are presented in table 1; table 2 presents the statistical analysis of the yield data. It can be seen from table 2 that the F value for the experiment is highly significant, indicating that there are highly significant

FIG. 2.

differences between the effects of the treatments on mean fruit weights. The results of the evaluation of the statistical significance of the mean fruit-weight differences that may be attributed to the various treatments tried are shown in table 1. These results indicate that the pineapple plants grown in the soil to which filter press cake had been added (treatment C), were the heaviest yielders, their yields being significantly superior at the 5-percent level to those of pineapple plants grown in soil with the pH

TABLE 1.—*Mean fruit weights of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Symbol	Treatments	Mean weight of fruit	Outyielded at—[1]	
			5-percent level	1-percent level
		Pounds		
A	Soil pH adjusted with lime to 6.2	3.54	—	—
B	Soil pH adjusted with lime to 7.2	3.17	—	—
C	Filter press cake mixed with soil	4.49	A–D	B
D	Ferrous sulfate spray applied to plants	3.52	—	—
E	Control—no treatment	3.85	—	—

[1] Least significant difference between mean weights of fruits at the 5-percent level, 0.89 lb.; at the 1-percent level, 1.20 lbs.

TABLE 2.—*Analyses for the total sum of squared deviations for mean fruit weights of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Source	Degrees of freedom	Sum of squares	Mean square	*F* value[1]
Total	49	29.6191		
Replications	9	2.1907		
Treatments	4	9.7195	2.4294	4.94*
Error	36	17.7089	.4919	

[1] One asterisk indicates significance at 5-percent level; two asterisks at 1-percent level in this and later tables.

adjusted with lime to 6.2 (treatment A) and to pineapple plants which received ferrous sulfate spray, treatment D (figure 3, A, C, D). These same filter-press-cake-treated plants were also significantly superior in

FIG. 2.—Vegetative growth made by pineapple plants by the end of approximately 11 months from planting: A, Soil pH adjusted with lime to 6.2; B, soil pH adjusted with lime to 7.2; C, filter press cake mixed with soil; D, ferrous sulfate spray applied to plants; and E, control—no treatment.

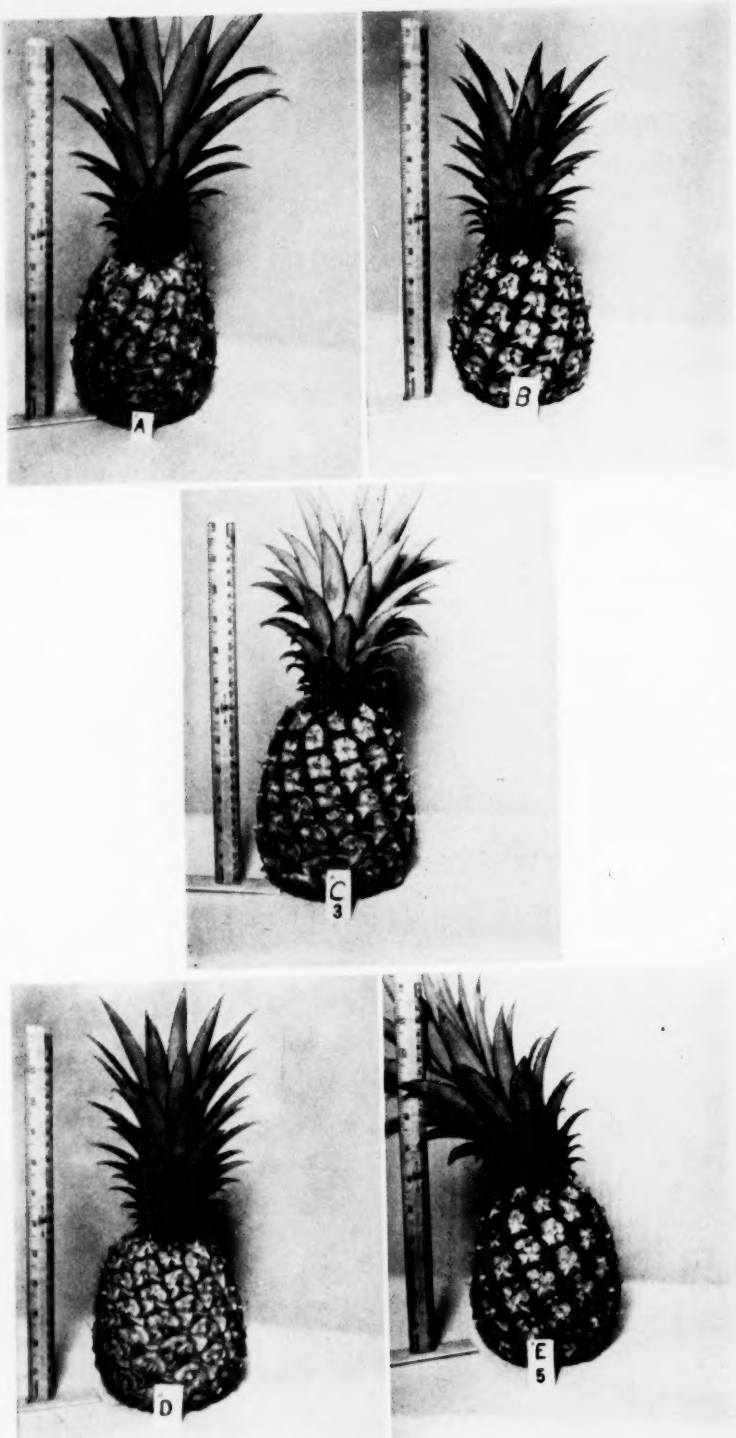

Fig. 3.

yield at the 1-percent level to the pineapple plants of treatment B, grown in soil where the pH was adjusted with lime to 7.2 (figure 3, B). It is also evident from table 1 that, except for the filter-press-cake treatment, no significant differences occurred between any of the other treatments considered in the experiment.

Effect of Treatments on Slip Production

The results gathered on the mean number of slips from plants undergoing the various treatments are shown in table 3; table 4 presents a summary of the statistical analysis of these data. It indicates that there are significant differences between the mean number of slips produced by the plants under the different treatments. The results of the evaluation

TABLE 3.—*Mean number of slips and of suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Symbol	Treatments	Mean number of slips	Outyielded at 5-percent level[1]	Mean number of suckers	Outyielded at 1-percent level[2]
A	Soil pH adjusted with lime to 6.2	4.2	—	1.6	—
B	Soil pH adjusted with lime to 7.2	4.2	—	1.3	—
C	Filter press cake mixed with soil	7.8	A–B	3.5	A–B–D–E
D	Ferrous sulfate spray applied to plants	5.3	—	1.9	—
E	Control—no treatment	5.7	—	1.8	—

[1] Least significant difference between mean number of slips at the 5-percent level, 3.36.

[2] Least significant difference between mean number of suckers at the 1-percent level, .96.

of the statistical significance of the differences in mean number of slips that may be attributed to the different treatments are presented in table 3. They indicate that the pineapple plants which developed in the soil to which filter press cake was added (treatment C) produced the greatest mean number of slips. However, they were significantly superior at the 5-percent level only to the slips produced by the plants of treatments A and B grown in soil that received lime to raise the pH to 6.2 and 7.2, respectively. There were no significant differences between the mean number of slips produced by plants that received other treatments.

FIG. 3.—Typical pineapple fruits and average weight of fruits obtained from plants subjected to the various treatments: A, Soil pH adjusted with lime to 6.2, 3.54 lbs.; B, soil pH adjusted with lime to 7.2, 3.17 lbs.; C, filter press cake mixed with soil, 4.49 lbs.; D, Ferrous sulfate spray applied to plants, 3.52 lbs.; and E, control—no treatment, 3.85 lbs.

Effect of Treatment on Sucker Production

The results obtained on the mean number of suckers in the different treatments are reported in table 3; a summary of the statistical analysis appears in table 4. As can be seen, the *F* value for the experiment is highly significant, showing that there were highly significant differences between the mean number of suckers produced by the pineapple plants under the various treatments. As a matter of fact, the *F* value obtained for the mean number of suckers was a little over 6 times the actual *F* value required for odds of 99.1, thus underlining the effect of treatments on the production of suckers by pineapple plants. It is evident from table 3 that the filter-press-cake-treated plants (treatment C) were superior in production of

TABLE 4.—*Analyses for the total sum of squared deviations for mean number of slips and suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Source	Degrees of freedom	Sum of squares	Mean square	*F* value
		Slips		
Total	49	343.68		
Replications	9	15.52		
Treatments	4	87.32	21.83	3.26*
Error	36	240.84	6.69	
		Suckers		
Total	49	44.98		
Replications	9	4.18		
Treatments	4	29.48	7.37	23.77**
Error	36	11.32	.31	

suckers to those undergoing other treatments, and in a highly significant way. This demonstrates that the filter-press-cake amendment had a beneficial effect on sucker production. There was no significant difference between the results of other treatments. The suckers of the filter-press-cake-treated plants developed much earlier than the suckers from plants that underwent other treatments.

Effect of Soil pH on Weight of Fruits, Number of Slips, and Number of Suckers

To determine the possible effect of soil pH on fruit yields, and slip and sucker production of pineapple plants under the various treatments, a

regression study was made of the above-mentioned criteria on soil pH. Soil samples were taken from each replicate of each treatment at depths of 0–3 inches and 3–6 inches, respectively; pH determinations were made using a glass electrode. Table 5 presents the results of the regression studies. It can be seen that the regressions were all significant either at the 5- or 1-percent level. They were all highly significant at the 1-percent level at the 0–3-inch soil depth. Therefore, under the conditions of this experiment, this soil depth is the better of the two studied for regression studies of the weight of fruits, number of slips, and number of suckers on soil pH. Since the regression coefficients are negative, there was an inverse relation between soil pH and the growth criteria being considered.

The regressions of weight of fruits, number of slips, and number of suckers on soil pH are shown in figure 4. To avoid plotting each fruit weight, number of slips, and number of suckers with reference to each pH

TABLE 5.—*Results of regression studies of weight of fruits, number of slips, and number of suckers on soil pH at two soil depths; experiment in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Criteria	Regression coefficient at soil depth of—		Percentage of sum of squares explained by regression at soil depth of—		Number of observations
	0–3 inches	3–6 inches	0–3 inches	3–6 inches	
			Percent	*Percent*	
Weight of fruits	−0.319**	−0.310**	21.0	16.0	50
Number of slips	− .904**	− .827**	14.0	10.0	50
Number of suckers	− .470**	− .452**	29.0	22.0	50

reading obtained, the pH values and the different criteria considered were grouped arbitrarily according to pH ranges and mean weight of fruits, mean number of slips, and mean number of suckers as is shown in table 6.

In figure 4 it may be clearly seen that weight of fruits, number of slips, and number of suckers produced by pineapple plants were adversely affected by increments of soil pH. In other words, increases in fruit yields as well as in slip and sucker production were inversely proportional to increments in soil pH. Thus an acid reaction of the soil medium tended to favor plant response in all respects.

Effect of Treatments on Weight of Fruits, Number of Slips, and Number of Suckers, Eliminating Soil pH Effect

To study the effects of the different treatments divorced from their pH effect on the mean weight of fruits, mean number of slips, and mean number

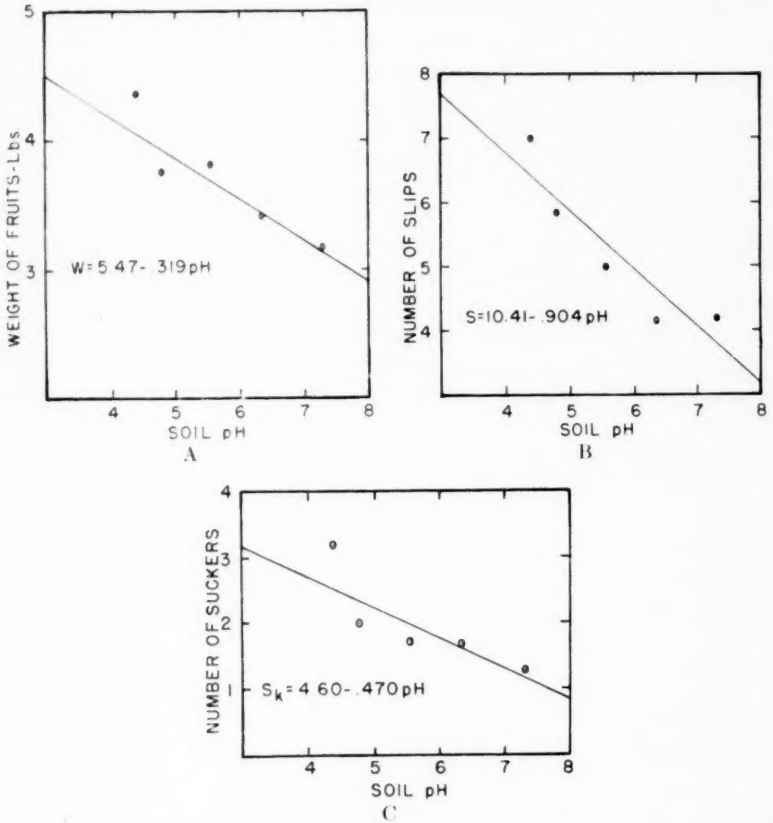

FIG. 4.—Regressions of weight of fruits (A), number of slips (B), and number of suckers (C) on soil pH at 0–3 inches soil depth; experiment in Bayamón silty clay from Palo Blanco, Arecibo.

TABLE 6.—*Summary of criteria considered in regressions of weight of fruits and numbers of slips and suckers; experiment in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Number of plots	pH range	Mean pH	Mean yield per fruit	Mean number of slips	Mean number of suckers
			Pounds		
10	3.91–4.60	4.46	4.35	7.00	3.20
17	4.61–5.00	4.77	3.74	5.88	2.00
7	5.01–6.00	5.39	3.80	5.00	1.71
6	6.01–7.00	6.26	3.42	4.17	1.67
10	7.01–7.50	7.24	3.17	4.20	1.30

TABLE 7.—*Summary of covariance analyses for mean fruit weights of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Symbol	Treatments	Adjusted mean weight of plants	Deviations from control	Least significant deviation at 5-percent level
		Pounds	*Pounds*	
A	Soil pH adjusted with lime to 6.2	3.726	0.036	1.398
B	Soil pH adjusted with lime to 7.2	3.595	− .095	2.395
C	Filter press cake mixed with soil	4.234	.544	.760
D	Ferrous sulfate spray applied to plants	3.350	− .340	.646
E	Control—no treatment	3.690	—	—

TABLE 8.—*Summary of covariance analyses for mean number of slips of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Symbol	Treatments	Adjusted mean number of slips	Deviations from control	Least significant deviation at 5-percent level
A	Soil pH adjusted with lime to 6.2	4.040	−1.692	5.150
B	Soil pH adjusted with lime to 7.2	3.939	−1.857	8.824
C	Filter press cake mixed with soil	7.959	2.163	2.799
D	Ferrous sulfate spray applied to plants	5.403	− .393	2.377
E	Control—no treatment	5.796	—	—

TABLE 9.—*Summary of covariance analyses for mean number of suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Symbol	Treatments	Adjusted mean number of suckers	Deviations from control	Least significant deviations at—	
				5-percent level	1-percent level
A	Soil pH adjusted with lime to 6.2	1.352	−0.697	1.104	—
B	Soil pH adjusted with lime to 7.2	.624	−1.425	1.893	—
C	Filter press cake mixed with soil	3.910	1.861	.600	0.805
D	Ferrous sulfate spray applied to plants	2.105	.116	.510	—
E	Control—no treatment	2.049	—	—	—

of suckers, a covariance analysis was made eliminating the effect of variations on soil pH; tables 7, 8, and 9 present the results.

It appears from tables 7 and 8 that none of the treatments had an

effect on mean weight of fruits or mean number of slips, when the effect of pH was disregarded. In other words, the possible detrimental effect that lime might have as a nutrient or otherwise, or the possible beneficial effect of filter press cake or iron spray to plants, were not evident when the pH effect was disregarded. On the other hand, table 9 indicates that when the pH effect is disregarded, filter press cake was the only factor that had a highly significant effect on the number of suckers produced by the pineapple plants undergoing this treatment. This indicated that some factor other than pH was also responsible for the high sucker production under this treatment. This point will be considered in detail in the discussion.

TABLE 10.—*Total and soluble iron and manganese content of midsection of active center leaves of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo*

[Plant crop]

Symbol	Treatments	Total iron	Soluble iron	Soluble iron to total iron	Total manganese	Soluble manganese	Soluble manganese to total manganese	Ratio Fe/Mn, soluble
		P.p.m.	*P.p.m.*	*Per cent*	*P.p.m.*	*P.p.m.*	*Per cent*	
A	Soil pH adjusted with lime to 6.2	140	—	—	330	294	89.09	—
B	Soil pH adjusted with lime to 7.2	193	74	38.34	330	256	77.58	1:3.5
C	Filter press cake mixed with soil	158	69	43.67	270	189	70.00	1:2.7
D	Ferrous sulfate spray applied to plants	114	34	29.82	360	213	59.17	1:6.3
E	Control—no treatment	123	46	37.39	450	375	83.33	1:8.2

Results of Chemical Analyses of Leaf Tissue Fractions

The results of quantitative analyses for total and soluble iron and manganese of the midsection fractions of active leaves of pineapple plants in the various treatments are presented in table 10. They provide no conclusive evidence of a direct relationship between the iron and manganese content of the plant tissues analyzed and yields of pineapples reported in table 1. It is of interest to note in table 10 that a relatively large proportion of the total manganese in the midsection of active leaves of pineapple plants is soluble whereas the reverse is true of the total iron therein.

EXPERIMENT ON FAJARDO CLAY

EXPERIMENTAL RESULTS AND STATISTICAL INTERPRETATION

Effect of Treatments on Plant Growth

Pineapple plants which were grown in soil treated with filter press cake made more vegetative growth and were darker green than those given other

treatments. The stems of these filter-press-cake-treated plants were thicker and their leaves wider and larger than those of the other plants. All the filter-press-cake-treated plants had developed suckers just before being treated with acetylene, showing earliness in this respect (figure 5). This was true also of plants similarly treated but grown in Bayamón silty clay. Pineapple plants which received lime as a soil remedial treatment were of a light-green color, which was more pronounced in those growing in soil that was limed to raise the pH to 7.2. Even the check plants looked better in all respects than the lime-treated plants. In short, these plants were the most vigorous of all and were similar to those treated with filter press cake in the experiment reported above. (Figure 6, A, C, D.)

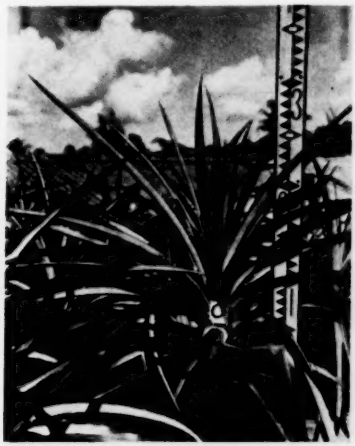

FIG. 5.—Pineapple plant grown in soil with which filter press cake had been mixed. Note developing sucker at lower left side of stem.

Effect of Treatments on Fruit Yields

The results on the mean weight of fruits undergoing the different treatments are presented in table 11; table 12 presents the statistical analysis of this fruit data. Table 12 shows that there were highly significant differences between the mean fruit weights of plants grown under different treatments. Table 11 also shows the results of the evaluation of the statistical significance of the mean-fruit-weight differences attributable to the various treatments. It appears from these data that the pineapple plants grown in soil mixed with filter press cake (treatment C) produced the greatest mean weight of fruits, this mean weight being significantly superior at the 5-percent level to that of pineapple plants grown in limed soil to raise the pH to 6.2 (treatment A) and to the check plants of treatment E. Also the fruit yields of these filter-press-cake-treated plants were

superior at the 1-percent level to the yields of plants from treatment B where the soil was limed to raise its pH to 7.2, and to those of treatment D,

FIG. 6.—Vegetative growth made by pineapple plants approximately 11 months from planting: A, Soil pH adjusted with lime to 6.2; C, filter press cake mixed with soil; and D, ferrous sulfate spray applied to plants. (Treatments B and E not shown.)

which received a ferrous sulfate spray. No significant difference was evident between the mean fruit weights of the plants in the other treatments.

Effect of Treatments on Slip Production

The data on the mean number of slips produced under the different treatments are reported in table 13; table 14 summarizes the statistical

TABLE 11.—*Mean fruit weight of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Symbol	Treatments	Mean weight of fruits	Outyielded at[1]	
			5-percent level	1-percent level
		Pounds		
A	Soil pH adjusted with lime to 6.2	3.33	—	—
B	Soil pH adjusted with lime to 7.2	3.27	—	—
C	Filter press cake mixed with soil	4.47	A–E	B–D
D	Ferrous sulfate spray applied to plants	2.94	—	—
E	Control—no treatment	3.60	—	—

[1] Least significant difference between mean weights of fruits at the 5-percent level, 0.86 lb.; at the 1-percent level, 1.15 lbs.

TABLE 12.—*Analyses for the total sum of squared deviations for mean fruit weight of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Source	Degrees of freedom	Sum of squares	Mean squares	*F* value
Total	49	32.5398		
Replications	9	2.9297		
Treatments	4	13.3720	3.3430	7.41**
Error	36	16.2381	.4511	

TABLE 13.—*Mean number of slips and of suckers of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Symbol	Treatments	Mean number of slips	Outyielded at 5-percent level[1]	Mean number of suckers	Outyielded at 1-percent level[2]
A	Soil pH adjusted with lime to 6.2	3.6	—	1.7	—
B	Soil pH adjusted with lime to 7.2	4.2	—	1.2	—
C	Filter press cake mixed with soil	6.2	A	3.1	A–B–D–E
D	Ferrous sulfate spray applied to plants	3.9	—	1.0	—
E	Control—no treatment	4.9	—	1.7	—

[1] Least significant difference between mean number of slips at the 5-percent level, 2.31.

[2] Least significant difference between mean number of suckers at the 1-percent level, 1.21.

analysis of these data. It is clear that the results were significant as regards slip production, since the *F* value obtained experimentally was greater

than that required to give odds of 19:1. The results of the evaluation of the statistical significance of differences between the mean number of slips that may be attributed to the various treatments are reported in table 13. It is evident that the pineapple plants treated with filter press cake (treatment C) were superior in slip production to those treated otherwise, but were significantly superior only at the 5-percent level to the slips produced by pineapple plants of treatment A grown in soil that was limed to a pH of 6.2. No significant differences were observed in slip production that could be ascribed to other treatments.

TABLE 14.—*Analyses for the total sum of squared deviations for mean number of slips of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Source	Degrees of freedom	Sum of squares	Mean square	*F* value
Total	49	204.32		
Replications	9	44.72		
Treatments	4	42.92	10.73	3.31*
Error	36	116.68	3.24	

TABLE 15.—*Analyses for the total sum of squared deviations for mean number of suckers of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Source	Degrees of freedom	Sum of squares	Mean square	*F* value
Total	49	47.62		
Replications	9	2.82		
Treatments	4	26.92	6.730	13.54**
Error	36	17.88	.497	

Effect of Treatments on Sucker Production

Table 13 presents the data on the mean number of suckers of the pineapple plants from each treatment; table 15 reports a summary of the statistical analysis of these data. This summary indicates that there are highly significant differences in sucker production by the pineapple plants undergoing the different treatments. Table 13 shows the evaluation of the statistical significance of mean number of suckers as a result of the treatments. The pineapple plants grown in soil mixed with filter press cake (treatment C) again surpassed those undergoing other treatments in sucker production, and in a highly significant way. It is also evident that differences in sucker production between the plants of other treatments were

not significant. Again suckers arising from the plants treated with filter press cake were considerably more developed than those of plants undergoing other treatments.

Effect of Soil pH on Weight of Fruits, Number of Slips, and Number of Suckers

As was done in the other experiment, a regression study was made to find the possible effect of soil pH on fruit weight, and slip and sucker production. The same procedure was followed for taking soil samples at various depths and readings in the glass electrode as for the soil of the first experiment. Table 16 shows the results of these regression studies. With only one exception, which fell short of a significant value, the regression coefficients on soil pH of the three criteria considered were all significant also. As in the first experiment, the regression coefficients were negative,

TABLE 16.—*Results of regression studies of weight of fruits, number of slips, and number of suckers on soil pH at two soil depths; experiment in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Criteria	Regression coefficient at soil depth of—		Percentage of sum of squares explained by regression at soil depth of—		Number of observations
	0–3 inches	3–6 inches	0–3 inches	3–6 inches	
Weight of fruits	−0.245*	−0.317*	12.0	9.0	50
Number of slips	− .472	− .905*	7.0	11.0	50
Number of suckers	− .346**	− .474*	17.0	12.0	50

indicating that there is an inverse relation between soil pH and the criteria under consideration.

The regression of weight of fruits and number of suckers on soil pH at 0–3-inch soil depth is presented in figure 7. To avoid plotting each fruit weight and number of suckers with respect to each pH value obtained, the same procedure was followed as for the experiment already reported. The values for pH's and the various criteria considered were grouped arbitrarily according to pH ranges, mean weight of fruits, and mean number of suckers as reported in table 17.

The summary presented and figure 7 shows that, as a whole, the mean yield of fruits and the mean number of suckers produced by the pineapple plants were again adversely affected by increased soil alkalinity. Under the conditions of the experiment, increases in fruit yields and sucker production were again inversely correlated with increments in soil pH. Similar results have been obtained with respect to fruit yields and pH studies (8).

Effect of Treatments on Weight of Fruits, Number of Slips, and Number of Suckers, Eliminating Soil pH Effect

As in the previous experiment, covariance analyses were made to study the effect of the various treatments on mean weight of fruits, mean number

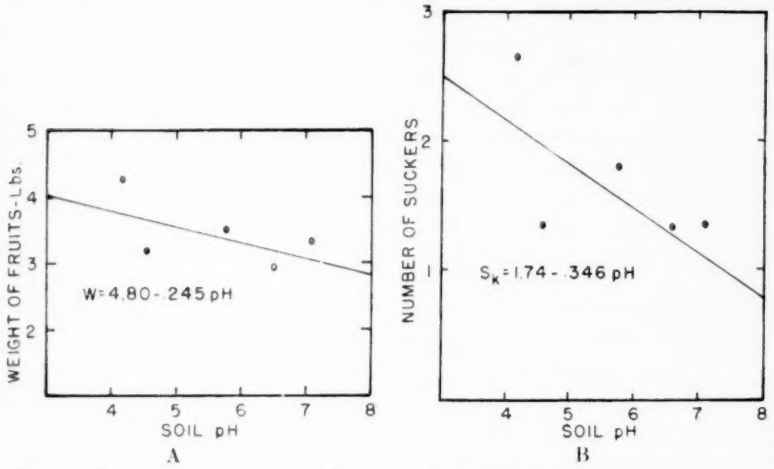

FIG. 7.—Regressions of weight of fruits (A), and number of suckers (B) on soil pH at 0-3 inches soil depth; experiment in Fajardo clay from Experiment Station Farm, Río Piedras.

TABLE 17.—*Summary of criteria considered in regressions of weight of fruits and number of suckers; experiment in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Number of plots	pH range	Mean pH	Mean yield per fruit	Mean number of suckers
			Pounds	
14	3.81–4.40	4.14	4.25	2.64
17	4.41–5.00	4.57	3.20	1.35
5	5.01–6.10	5.59	3.53	1.80
6	6.11–6.90	6.51	2.94	1.33
8	6.91–7.32	7.12	3.37	1.25

of slips, and mean number of suckers, when the effects of soil pH were disregarded. Tables 18 and 19 report the results of these.

Contrary to expectations, it appears that the iron spray was detrimental to fruit and sucker production at the 5-percent level, when the effect of pH was ignored. In the previous experiment the iron spray had neither favorable nor unfavorable effects on the pineapple plant life cycle. None of

the treatments (table 19) had any effect on slip production when pH was ignored. This is consistent with results obtained in the first experiment.

TABLE 18.—*Summary of covariance analyses for mean fruit weights of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Symbol	Treatments	Adjusted mean weight of fruits	Deviations from control	Least significant deviations at—	
				5-per-cent level	1-per-cent level
		Pounds	*Pounds*		
A	Soil pH adjusted with lime to 6.2	3.827	0.643	1.066	—
B	Soil pH adjusted with lime to 7.2	4.362	1.178	1.588	—
C	Filter press cake mixed with soil	3.759	.575	.646	—
D	Ferrous sulfate spray applied to plants	2.476	− .708	.584	.784
E	Control—no treatment	3.184	—	—	—

TABLE 19.—*Summary of covariance analyses for mean number of slips and of suckers of pineapple plants grown in Fajardo clay from Experiment Station Farm, Río Piedras*

[Plant crop]

Symbol	Treatments	Adjusted mean number of slips	Deviations from control	Least significant deviations at—	
				5-percent level	1-percent level
	Slips				
A	Soil pH adjusted with lime to 6.2	4.196	−0.199	3.000	—
B	Soil pH adjusted with lime to 7.2	5.517	1.122	4.470	—
C	Filter press cake mixed with soil	5.349	.954	1.819	—
D	Ferrous sulfate spray applied to plants	3.342	−1.053	1.644	—
E	Control—no treatment	4.395	—	—	—
	Suckers				
A	Soil pH adjusted with lime to 6.2	2.008	0.570	1.164	—
B	Soil pH adjusted with lime to 7.2	1.881	.443	1.735	—
C	Filter press cake mixed with soil	2.659	1.221	.706	0.948
D	Ferrous sulfate spray applied to plants	.711	− .727	.638	.856
E	Control—no treatment	1.438	—	—	—

From table 19 it appears again that filter press cake was the only factor producing a highly significant effect on the number of suckers produced by the pineapple plants in this treatment, which suggests that some factor other than pH was a contributing agent in promoting a better production of suckers.

Results of Chemical Analyses of Leaf Tissue Fractions

Table 20 reports the results of quantitative analyses for total and soluble iron and manganese of the midsection of active leaves from pineapple plants under the different treatments. The data do not indicate any definite relationship between the iron and manganese content of the plant tissues analyzed and yields of pineapples. It can also be seen that a relatively higher proportion of total manganese was in the soluble form, the reverse being true for total iron.

TABLE 20.—*Total and soluble iron and manganese content of midsection of active center leaves of pineapple plants grown in Fajardo clay from Experiment Station Farm, Rio Piedras*

[Plant crop]

Symbol	Treatments	Total iron	Soluble iorn	Soluble iron to total iron	Total manganese	Soluble manganese	Soluble manganese to total manganese	Ratio Fe/Mn, soluble
		P.p.m.	*P.p.m.*	*Percent*	*P.p.m.*	*P.p.m.*	*Percent*	
A	Soil pH adjusted with lime to 6.2	324	45	13.89	390	307	78.72	1:6.8
B	Soil pH adjusted with lime to 7.2	271	148	54.61	240	163	67.92	1:1.10
C	Filter press cake mixed with soil	123	60	48.78	240	132	55.00	1:2.20
D	Ferrous sulfate spray applied to plants	149	49	32.89	120	71	59.17	1:1.45
E	Control—no treatment	140	62	44.29	180	109	60.56	1:1.76

General Discussion

The qualitative observations made on the growth of pineapple plants under the various treatments, as well as the quantitative evidence obtained on the different growth criteria considered in both pineapple experiments, revealed information of importance.

It was found in both pineapple experiments, that the plants treated with filter press cake produced more vigorous growth than plants undergoing other treatments. Moreover, they were greener in color, their leaves were wider, and their stems and flower stalks thicker than the corresponding organs of pineapple plants undergoing the other treatments, thus suggesting high yield.

With only one exception the filter-press-cake-treated plants produce significantly greater yields in both experiments than the plants undergoing other treatments. They were the largest plants of all and the ones having the thickest flower stalks. In other words, the size of plants and thickness of flower stalks were directly related to yield. It may logically be assumed

that a large plant with a large, thick flower stalk is capable of yielding a larger fruit because of higher food reserves than small plants with rather small, thin flower stalks, which presumably have a lower food-storage capacity.

It was found in both experiments that pineapple plants grown in soil with which filter press cake was mixed were superior in slip production to plants undergoing other treatments. However, they were significantly superior only to the lime-treated plants, thus showing the detrimental effect of the use of lime, not only on yield production, as mentioned before, but also on slip production. This suggests that the use of lime in pineapple growing is not a wise agricultural practice under present conditions.

It was evident that the filter-press-cake-treated plants in a highly significant way surpassed those undergoing other treatments in the number of suckers produced. This was true in both experiments. It was surprising to observe that the stem offshoots of the plants undergoing this treatment began to show much earlier than those of plants under other treatments. This, of course, was advantageous since these offshoots naturally had a longer period for growth and development, and consequently were better developed to produce a good ratoon crop. Whether the factor responsible for this early appearance of suckers is nutritional, or something else still remains to be investigated. As judged from the qualitative observations made on growth and development of the plants undergoing the various treatments, filter press cake seems to hasten the growth of pineapple plants. In other words, filter press cake tends to favor complete vegetative growth of pineapple plants until they are ready for the acetylene treatment.

The results obtained in both experiments showed conclusively that increases in fruit yields and slip and sucker production were favored by an acid reaction of the soil. These criteria of growth increased as soil pH decreased. Pennock reported similar results on fruit yields and pH studies (8). The theoretical assumption that raising the soil pH slightly above 6 would control the activity of available manganese in the soil and thus favor a better iron-manganese balance (which would be reflected in the metabolism of the pineapple plants and consequently in fruit yields, etc.) was not confirmed in these studies.

The quantitative chemical data presented for both available iron and manganese, and the corresponding ratios, do not provide any clear-cut information that relates fruit yields and other growth criteria here considered to iron and manganese relationships under field conditions. Unpublished data of the writer on iron-manganese studies with pineapples under field conditions point to the possibility that factors other than iron

and manganese adversely affect pineapple production, since there seems to be no interaction between lime and ferrous spray treatments in field experiments. This is in complete agreement with similar results obtained by Pennock in pineapple field studies (8). Moreover, the fact that the best yields of pineapples were obtained at relatively low soil acidity where manganese is supposed to be quite soluble (6) strengthens the assumption that factors other than iron and manganese are involved in adversely affecting pineapple production under field conditions. This does not mean that one should completely disregard the importance of the iron and manganese nutrition of pineapples, but it does show that the use of lime in pineapple growing to correct the adverse effects of iron-manganese imbalance is not a sound agricultural practice.

It was found that filter press cake decreased soil pH, lowering it to 4.42 for the Bayamón silty clay of Arecibo and to 4.11 for the Fajardo clay of Río Piedras, as compared with original values of 4.85 and 4.56, respectively, for the untreated soil of both experiments. With these pH's and a source of organic matter such as filter press cake, it is logical to assume that soil micro-organisms, principally soil fungi, were abundant, since it has been demonstrated that such soil microbes are closely associated with the decomposition of organic matter added to the soil (3, 13, 14). It is a well-known fact that organic matter improves soil texture and consequently permits better soil aeration. Since filter press cake is a source of organic matter, it may be assumed that it contributed in the better aeration of the soil, a factor that has been found (because it gives access to oxygen) to be vital for normal healthy root development and consequently for normal plant metabolism (2, 5, 11). Possibly filter press cake was also beneficial in helping prevent the leaching out of soluble nutrients added to the soil in the form of inorganic fertilizer, thus conserving nitrogen, available potash, phosphorus, and other plant nutrients for the pineapple plants.

The covariance analyses made to study the effects of treatments with soil pH effects disregarded indicated that none of them had any effect on yield or slip production in the experiment in Bayamón silty clay from Arecibo. However, in the experiment in Fajardo clay from Río Piedras, the covariance analyses did show to our surprise that the iron spray was significantly detrimental to both yield and slip production. Presumably some unknown factor or factors were responsible for the plants' reaction in this particular experiment. On the other hand, when the pH effect was disregarded, filter press cake was the only treatment which highly significantly influenced the production of suckers by pineapple plants in both experiments, thus showing that some other factor or factors played an important role in this respect.

Conclusion

The results presented for both pineapple experiments demonstrated the outstandingly beneficial effect of filter press cake and the detrimental effect of lime applications to pineapple soils. The vigorous growth and deep green color of pineapple plants grown in soil with which filter press cake was mixed, and the significant or highly significant results obtained in yield, number of slips, and number of suckers, strengthens the belief that agricultural practices in the Island may be modified or altered so as greatly to increase pineapple production.

Summary

This paper reports the results obtained in studies carried out to establish the relationship between iron and manganese imbalance in the soil and remedial treatments on pineapple growth, development, and production. In addition to lime carbonate, organic matter in the form of filter press cake was also tested as a soil remedial treatment. The experimental results may be summarized briefly as follows:

1. Pineapple plants grown in soil with the top 6 inches of which filter press cake had been mixed, developed vigorously and were of a dark green color. Their leaves were wider and their stems and flower stalks thicker than those of pineapple plants given other treatments.

2. Pineapple plants grown in soil treated with filter press cake produced more than plants given other treatments. With only one exception their yields were significantly or highly significantly larger than those of plants undergoing other treatments.

3. Pineapple plants grown in soil treated with filter press cake were superior in slip production to plants given other treatments, but were only significantly superior at the 5-percent level to those produced by the lime-treated plants.

4. Pineapple plants grown in soil treated with filter press cake were highly significantly superior in production of suckers to pineapple plants undergoing other treatments.

5. Regression studies revealed that fruit yields and slip and sucker production were inversely proportional to increments in soil pH. A relatively acid soil medium favored plant growth, development, and production.

6. Soil samples at 0–3 inches depth were found to be the best index for regression studies of weight of fruits and number of slips and number of suckers on soil pH.

7. Other than the soil pH, filter press cake was the only factor that had

a highly significant effect on the number of suckers produced by pineapple plants.

8. No relationship was found between the soluble iron and manganese contents of the midsection, center leaves of pineapple plants and yields.

9. The results suggest that the use of lime in pineapple growing is not a sound agricultural practice, insofar as the correction of soil iron-manganese imbalance, and its detrimental effects on the crop are concerned.

10. The results also underline the possibility that factors other than the availability of iron and manganese adversely affect pineapple production in the Island.

11. The use of filter press cake as a soil amendment in pineapple growing offers the opportunity of altering or modifying agricultural practices so as to increase pineapple production in the Island.

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THE BENEFICIAL EFFECT OF FILTER PRESS CAKE ON PINEAPPLE GROWTH, DEVELOPMENT, AND PRODUCTION

II. EFFECT ON THE RATOON CROP

Ernesto Hernández-Medina[1]

Introduction

In a previous paper (5),[2] studies were reported which had been undertaken in the effort to find some remedial treatment for the adverse effects of iron-manganese imbalance in the soil upon the growth, development, and production of pineapples in the plant crop. The results of these experiments demonstrated both qualitatively and quantitatively that filter press cake had an outstandingly beneficial effect on pineapple production, whereas applications of lime were markedly detrimental.

This paper reports on the effect on the ratoon crop of the same plant crop treatments.

Experimental Procedure

CULTURAL METHOD

The lay-out of the pineapple experiments, treatments tested and other information regarding set up of experiments have been presented previously (5).

All ratoon plants in the different treatments of both experiments received the same kind of commercial fertilizer as the plant crop at the rate of 1 ton per acre in two applications. The fertilizer was applied according to the ordinary procedures followed by the pineapple growers in their field plantings.

On November 21, 1949, leaf samples were taken from the plants representative of the various treatments for chemical determinations of total and soluble iron and manganese content of the tissue. The same procedure was followed for collecting leaf samples and preparing them for chemical analysis as for leaf samples obtained in the plant crop, except that only one leaf sample was used for determining both total and soluble iron and manganese, as will be explained in chemical methods.

On December 21, 1949, plants in both experiments were treated with

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[2] Numbers in parenthesis refer to Literature Cited, p. 301.

calcium carbide in solution to induce flower initiation and subsequently fruit production. The same procedure of application was followed as for the plant crop.

HARVESTING

The fruits of the ratoon plants of both pineapple experiments were harvested mainly in May and June of 1950, that is, 5 or 6 months after the plants were treated with acetylene. Other criteria of growth considered in the experimental results were slip and sucker production and green and dry weight of plants. After harvesting, soil samples were collected from the replicates of each treatments for determinations of pH, organic matter, total nitrogen, and available iron and manganese, and for soil-conductivity tests.

METHODS OF ANALYSIS

Plants

For determination of soluble iron and manganese in the leaf tissue fractions which were frozen after harvesting, the procedure used by Somers and Shive (10) was followed, with a few minor modifications for extraction of the cell sap in a Carver press. The frozen plant-leaf tissue after being thawed and wrapped in a piece of muslin was subjected to a pressure of 2,750 pounds per square inch for three consecutive periods totalling 4 minutes of extraction. Five milliliters of distilled water were added to the tissue during each extraction period to aid in the removal of the cell sap. The extracted juice was made to volume with water in a 50-ml. volumetric flask and was used for determinations of soluble iron and manganese. The press cake was dried and weighed and then ground in a semimicro Willey mill to be used for determinations of insoluble iron and manganese.

It is assumed in this work that the available iron and manganese in the leaves which were analyzed was that found in solution in the cell sap and which was extracted as completely as possible by pressure in a Carver press. On the other hand, the fractions of iron and manganese remaining in the press cake were regarded as the inactive or unavailable portions of these elements. Based on the above-mentioned procedure for determinations of iron and manganese in leaf-tissue samples, total iron and manganese were obtained by adding the quantity of iron and manganese found by analysis in the juice sample to the quantity found in the extracted leaf sample.

Wet digestion of aliquots of the extracted juice or of the ground tissue was carried out according to the procedure of Somers and Shive (10), but with some modifications. Aliquots of the juice or of the ground tissue were first wet-digested in 50-ml. Erlenmeyer flasks with 1 ml. of concentrated

sulfuric acid and 0.3 ml. of perchloric acid, followed by 0.5 ml. of hydrogen peroxide and, in some cases, by additional drops of this reagent until the solution was clear. After digestion the samples were transferred to 50-ml. volumetric flasks and made to volume. Iron and manganese were then determined by the same methods of analysis used for determining these elements in the plant crop (5).

Soils

Soil pH determinations were made using a Beckman glass electrode. Organic-matter content of the soil was determined by the rapid colorimetric method using the Cenco Wilde organic matter color Scale No. 28803, supplied by the Central Scientific Co., Chicago. Total nitrogen was determined by the Kjeldahl-Gunning method (1). Conductivity tests of soil samples were made following the procedure used by Bonnet et al. (4). Available iron was determined after extraction from the soil with Morgan's universal extracting solution, normal sodium acetate buffered at pH 4.8, with acetic acid as used for extraction of phosphorus from soil. The Saywell and Cunningham o-phenanthroline method was used for iron determination (9). Available or exchangeable manganese was run according to Peech's procedure and was determined by the periodate method of Peech (6).

In this report the results of both pineapple experiments will be considered together.

Experimental Results

PLANT GROWTH RESPONSE TO TREATMENTS

Throughout their growth period the ratoon plants which developed in the soil treated with filter press cake, in both types of soils, Bayamón silty clay from Arecibo and Fajardo clay from Río Piedras, surpassed the ratoon plants under other treatments in growth and development (figure 1). Though there were on an average three ratoon plants in each filter-press-cake replication, this was by no means a hindrance to plant growth and development. In fact, the filter-press-cake-treated plants were more vigorous and much better developed than ratoon plants under other treatments. Moreover, they were greener in color than any of the other ratoon plants, especially those in soil which received calcium carbonate to raise the pH to 7.2. As was the case with the filter-press-cake-treated plants of the plant crop (5), it was also easy to select the ratoon plants of this treatment since they were the tallest and best developed of all the plants.

EFFECT OF TREATMENTS ON FRUIT YIELD

The information gathered in both pineapple experiments on mean yield of fruits under each treatment is presented in table 1. The statistical

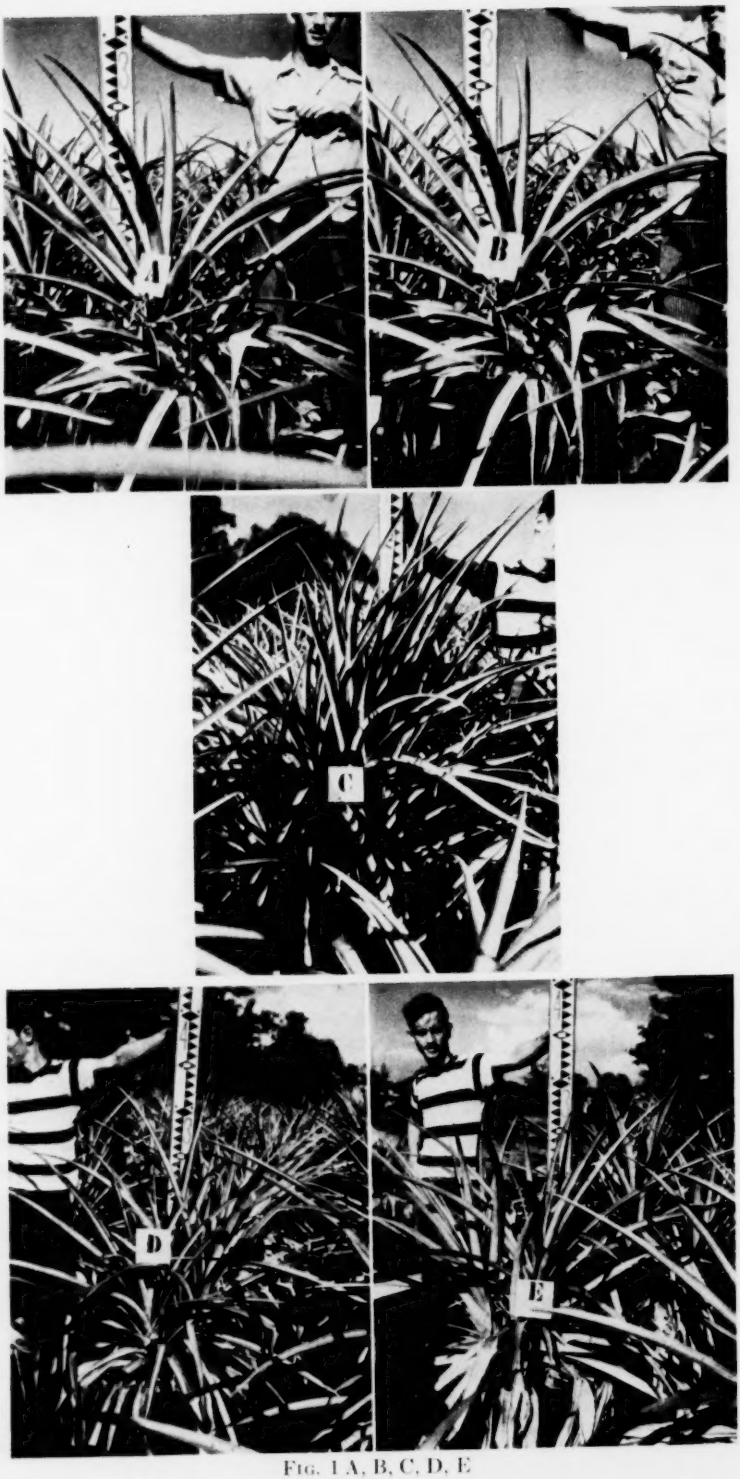

FIG. 1 A, B, C, D, E

analyses of the yield data indicated that there were highly significant differences between the mean fruit yields under different treatments. The results of the evaluation of the statistical significance of the mean fruit yield differences that may be attributed to the different treatments are also presented in table 1. They indicate that, in both the Arecibo and Río Piedras soils, the pineapple plants which developed in the substrate to which filter press cake was added yielded best, their yields being significantly superior at the 1-percent level to the yields of pineapple plants that underwent the other treatments. It is also evident from the yield

TABLE 1.—*Mean fruit yields of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Arecibo soil[1]		Río Piedras soil[1]	
		Mean yield of fruit	Outyielded at 1-percent level	Mean yield of fruit	Outyielded at 1-percent level
		Pounds		*Pounds*	
A	Soil pH adjusted with lime to 6.2	3.65	—	3.21	—
B	Soil pH adjusted with lime to 7.2	3.43	—	2.59	—
C	Filter press cake mixed with soil	7.08	A–B–D–E	5.84	A–B–D–E
D	Ferrous sulfate spray applied to plants	4.53	—	2.81	—
E	Control—no treatment	3.87	—	3.46	—

[1] Least significant difference between mean yield of fruits at the 1-percent level for Arecibo, 1.58 pounds; for Río Piedras, 2.20 pounds.

data for both experiments that, excluding the yields of the filter-press-cake-treated plants, there were no significant differences between the yields produced by pineapple plants undergoing other treatments.

SLIP PRODUCTION AS AFFECTED BY TREATMENTS

The data obtained on the mean number of slips for the various treatments, as well as the results of the evaluation of the statistical significance of the growth criteria that may be attributed to the various treatments, are shown in table 2. It is evident from these results that the pineapple plants grown in soil treated with filter press cake produced the greatest mean number of slips in both types of soils. However, in the Arecibo soil,

FIG. 1.—Vegetative growth made by ratoon pineapple plants prior to the application of calcium carbide to induce flowering: A, Soil pH adjusted with lime to 6.2; B, soil pH adjusted with lime to 7.2; C, filter press cake mixed with soil; D, ferrous sulfate spray applied to plants; and E, control—no treatment.

they were significantly superior at the 5-percent level only to the slips produced by the plants of treatment E (control) and significantly superior at the 1-percent level to the slips produced by the plants of treatment A whose soil was limed to raise the pH to 6.2. In the Río Piedras soil, the filter-press-cake-treated plants were significantly superior in number of slips produced at the 5-percent level only to the plants of treatment A, whose soil received lime to raise the pH to 6.2. This significance should not be taken as definite but as casual, since the experiment in itself was not significant. In other words, the *F* value obtained for the experiment was 1.59 while the required *F* value needed for significance was 2.65. It is

TABLE 2.—*Mean number of slips of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Arecibo soil[1]			Río Piedras soil[2]	
		Mean number of slips	Outnumbered at—		Mean number of slips	Outnumbered at 5-percent level
			5-percent level	1-percent level		
A	Soil pH adjusted with lime to 6.2	0.1	—	—	0.1	—
B	Soil pH adjusted with lime to 7.2	1.8	A	—	.4	—
C	Filter press cake mixed with soil	2.3	E	A	1.3	A
D	Ferrous sulfate spray applied to plants	.9	—	—	.5	—
E	Control—no treatment	.2	—	—	1.1	—

[1] Least significant difference between mean number of slips for Arecibo at 5-percent level, 1.7 slips; at 1-percent level, 2.2 slips.

[2] Least significant difference between mean number of slips for Río Piedras at 5-percent level, 1.1 slips.

also evident from the experimental results presented that, except for one case and in only one of the experiments, no significant difference was obtained between the mean number of slips produced by the pineapple plants of other treatments.

SUCKER PRODUCTION AS AFFECTED BY TREATMENTS

Table 3 shows the results gathered on the production of suckers by the pineapple plants undergoing the various treatments, and also the evaluation of the statistical significance of the mean number of suckers that may be attributed to the various treatments. The filter-press-cake-treated plants in both type of soils were superior in production of suckers, either significantly or highly significantly, to the plants of all other treatments.

In the Arecibo soil even the control plants (treatment E) produced significantly more suckers than the plants of treatment A, grown in soil that was limed to raise the pH to 6.2. Outside of this no significant difference was obtained in sucker production between the plants undergoing all other treatments in both pineapple experiments.

TABLE 3.—*Mean number of suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Arecibo soil[1]			Río Piedras soil[2]		
		Mean number of suckers	Outnumbered at—		Mean number of suckers	Outnumbered at—	
			5-percent level	1-percent level		5-percent level	1-percent level
A	Soil pH adjusted with lime to 6.2	1.1	—	—	1.2	—	—
B	Soil pH adjusted with lime to 7.2	1.6	—	—	.7	—	—
C	Filter press cake mixed with soil	3.0	E	A–B–D	2.5	D	A–B–E
D	Ferrous sulfate spray applied to plants	1.7	—	—	1.4	—	—
E	Control—no treatment	2.0	A	—	1.2	—	—

[1] Least significant difference between mean number of suckers for Arecibo at 5-percent level, 0.86 sucker; at 1-percent level, 1.15 suckers.

[2] Least significant difference between mean number of suckers for Río Piedras at 5-percent level, 1.02 suckers; at 1-percent level, 1.36 suckers.

GREEN AND DRY WEIGHT OF PLANTS AS INFLUENCED BY TREATMENTS

After the ratoon fruits were harvested, the green and dry weights of the whole tops of the pineapple plants were obtained to find out whether there was any relation between weight of plants and their yields. The data for both pineapple experiments are presented in table 4. The results of the evaluation of the statistical significance of the green and dry weights of the plants as a consequence of treatment are also reported in table 4. They indicate that the pineapple plants grown in soil that was treated with filter press cake (treatment C) produced the greatest mean green and dry weights of plants. These green and dry weights were superior in a highly significant way to the green and dry weights of plants subjected to other treatments. It should be recalled that these were the plants which produced the heaviest fruit yields, slips, and suckers. It is also evident from the results presented that with only one exception (dry weight of untreated plants superior at the 5-percent level to dry weights of limed

plants—Arecibo soil experiment), there were no significant differences between green and dry weights of plants representative of other treatments.

TABLE 4.—*Results of statistical analyses of mean green and dry weights of tops of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Mean green weight of plants	Outweighed at 1-percent level	Mean dry weight of plants	Outweighed at—		Dry weight of plants
					5-percent level	1-percent level	
	Bayamon silty clay, Palo Blanco, Arecibo[1]						
		Pounds		*Pounds*			*Percent*
A	Soil pH adjusted with lime to 6.2	5.77	—	1.61	—	—	27.85
B	Soil pH adjusted with lime to 7.2	5.38	—	1.53	—	—	27.47
C	Filter press cake mixed with soil	13.82	A–B–D–E	4.56	—	A–B–D–E	32.97
D	Ferrous sulfate spray applied to plants	7.40	—	1.76	—	—	23.76
E	Control—no treatment	7.45	—	2.33	A–B	—	31.32
	Fajardo clay, Experiment Station Farm, Rio Piedras[2]						
A	Soil pH adjusted with lime to 6.2	4.60	—	1.31	—	—	28.37
B	Soil pH adjusted with lime to 7.2	4.12	—	1.21	—	—	29.42
C	Filter press cake mixed with soil	10.09	A–B–D–E	2.88	—	A–B–D–E	28.55
D	Ferrous sulfate spray applied to plants	5.55	—	1.25	—	—	22.56
E	Control—no treatment	5.66	—	1.47	—	—	26.02

[1] Least significant difference between mean green weight of plants for Arecibo at the 1-percent level, 3.04 pounds; between mean dry weight of plants at the 5-percent level, 0.65 pound; at the 1-percent level, 0.87 pound.

[2] Least significant difference between mean green weight of plants for Río Piedras at the 1-percent level, 2.77 pounds; between mean dry weight of plants at the 1-percent level, 0.89 pound.

EFFECT OF SOIL pH ON YIELD OF FRUITS, NUMBER OF SLIPS, NUMBER AND WEIGHT OF SUCKERS, AND GREEN AND DRY WEIGHTS OF PLANTS

As was done with the growth criteria of the plant-crop pineapple experiments, a regression study was also made with the ratoon-crop pine-

apple experiments to find out the possible effect of soil pH on fruit yield, slip and sucker production, weight of suckers, and green and dry weights of plants. Table 5 reports the results of the regression studies. It is clear that with only two exceptions, in the Arecibo soil experiment, the regression coefficients on soil pH of the six criteria considered were all significant either at the 5- or 1-percent level. As in the plant-crop regression studies, the regression coefficients were all negative, indicating that there was an inverse relation between soil pH and the growth criteria considered.

The regressions of yield of fruits, number of suckers, and green and dry weights of plants on soil pH in the Arecibo soil experiment are shown in figure 2. To avoid plotting each fruit yield, number of suckers, and green and dry weights of plants with reference to each pH value obtained, the

TABLE 5.—*Results of regression studies of various growth criteria on soil pH for experiments in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Criteria	Arecibo soil experiment regression coefficient[1]	Río Piedras soil experiment regression coefficient[1]	Observations
			Number
Yield of fruits	−0.872*	−0.734**	50
Number of slips	− .066	− .334*	50
Number of suckers	− .348*	− .471**	50
Weight of suckers	− .113	− .212*	50
Green weight of plants	−1.860**	−1.491**	50
Dry weight of plants	− .653**	− .392**	50

[1] One asterisk indicates significance, two asterisks high significance in this and later tables.

same procedure was followed as for the pH values and growth criteria of the plant crop (5), that is, the pH's values and the different criteria under consideration were grouped arbitrarily according to pH ranges and mean yield of fruits, mean number of suckers, and mean green and dry weights of plants. A summary of such grouping is presented in table 6.

It is clear from the summary presented and figure 2, that yield of fruits, number of suckers, and green and dry weights of plants were again adversely affected by increments of soil pH or increased alkalinity of the soil. In other words, increase in soil pH reduced fruit yields, number of suckers, and green and dry weights of plants.

The regressions of yield of fruits, number of slips, number of suckers, weight of suckers, and green and dry weights of plants on soil pH of the Río Piedras soil experiment are presented in figure 3. The same procedure was followed as for the Arecibo soil experiment in grouping pH values

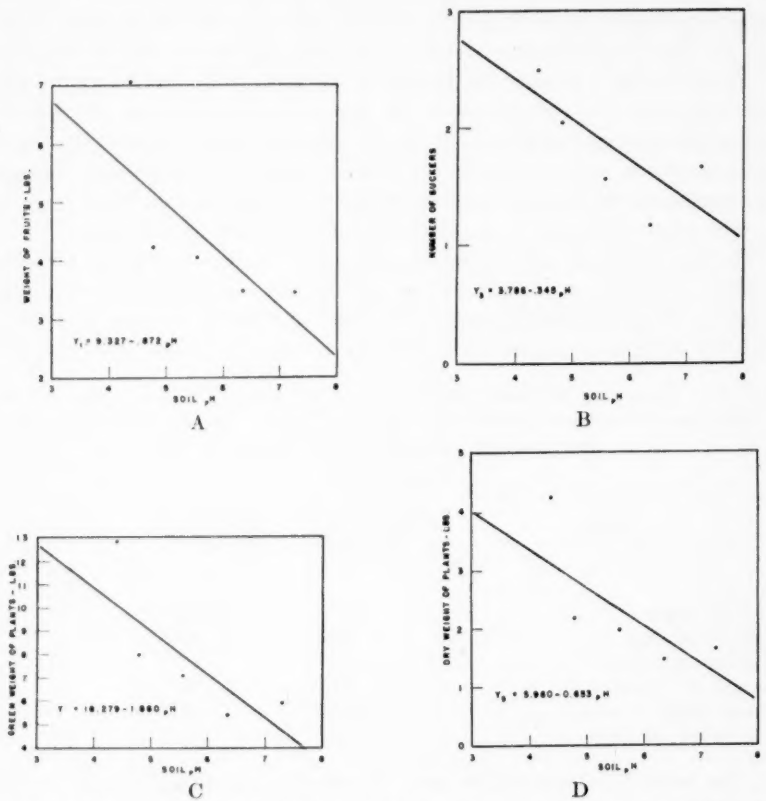

FIG. 2.—Regressions of weight of fruits (A), number of suckers (B), and green and dry weights of plants (C, D) on soil pH at 0–3 inches soil depth; experiment in Bayamón silty clay from Palo Blanco, Arecibo.

TABLE 6.—*Summary of criteria considered in regressions of yield of fruits, number of suckers, and green and dry weights of plants; experiment in Bayamón silty clay from Palo Blanco, Arecibo*

[Ratoon crop]

Number of plots	pH range	Mean pH	Mean fruit yield per plant or replication	Mean number of suckers	Mean green weight of plants	Mean dry weight of plants
			Pounds		*Pounds*	*Pounds*
10	3.91–4.60	4.46	7.08	2.50	12.84	4.22
17	4.61–5.00	4.77	4.21	2.06	7.84	2.19
7	5.01–6.00	5.39	4.09	1.57	7.02	1.97
6	6.01–7.00	6.26	3.47	1.17	5.46	1.46
10	7.01–7.50	7.24	3.42	1.67	5.84	1.63

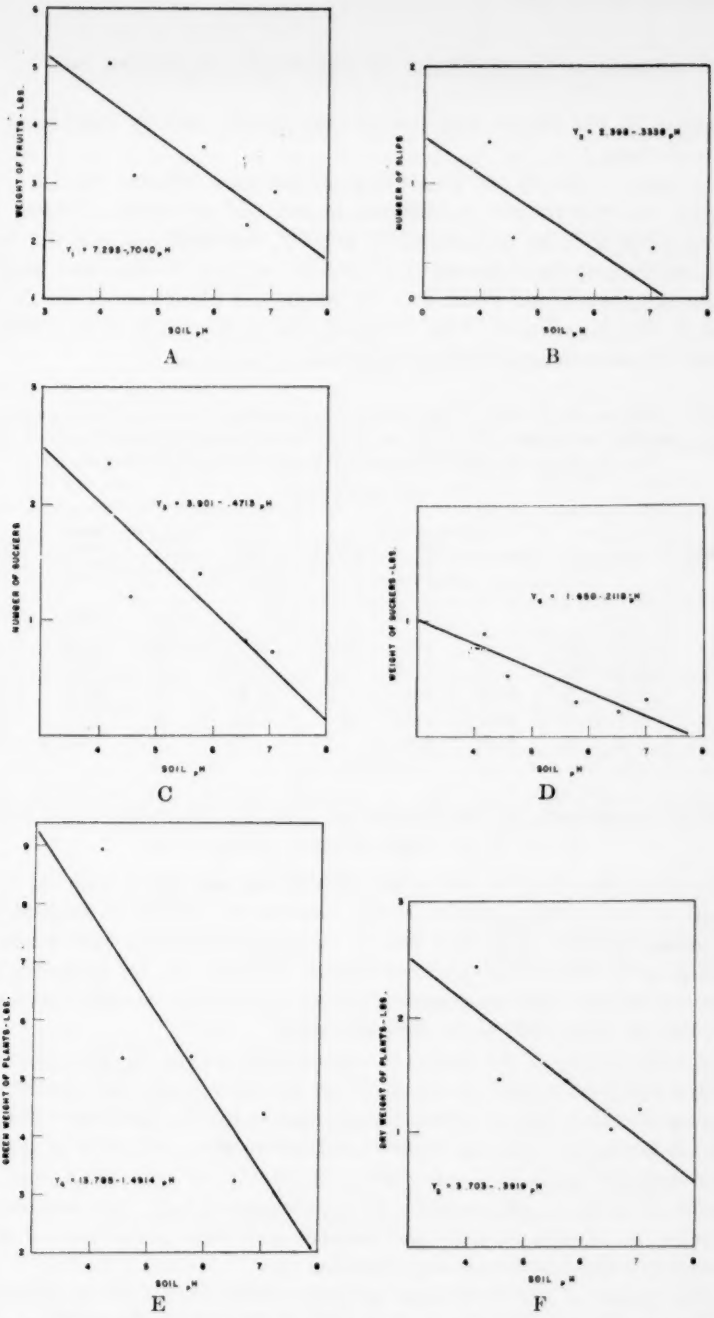

FIG. 3.—Regressions of weight of fruits (A), number of slips (B), number and weight of suckers (C, D), and green and dry weights of plants (E, F) on soil pH at 0–3 inches soil depth; experiment in Fajardo clay from Experiment Station farm Río Piedras.

according to pH ranges and the various growth criteria considered as shown in table 7.

The data in table 7 and figure 3, show the same definite trend for the Arecibo soil experiment; increments in soil pH adversely affected the growth criteria under discussion. In general, increments in soil pH were responsible again for lowering fruit yields, number of slips and suckers weight of suckers, and green and dry weights of plants under the conditions of this experiment. This indicates that a relatively acid condition of the substrate favored plant metabolism.

TABLE 7.—*Summary of criteria considered in regressions of yield of fruits, number of slips, number and weight of suckers, and green and dry weight of plants; experiment in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Number of plots	pH range	Mean pH	Mean fruit yield per plant or replication	Mean number of slips	Mean number of suckers	Mean weight of suckers	Mean green weight of plants	Mean dry weight of plants
			Pounds			*Grams*	*Pounds*	*Pounds*
14	3.81–4.40	4.14	5.07	1.36	2.36	0.90	8.94	2.45
17	4.41–5.00	4.57	3.18	.53	1.20	.54	5.37	1.47
5	5.01–6.10	5.59	3.65	.20	1.40	.30	5.39	1.44
6	6.11–6.90	6.51	2.30	0	.83	.21	3.25	1.02
8	6.91–7.32	7.12	2.84	.43	.71	.32	4.40	1.20

GROWTH CRITERIA AS INFLUENCED BY TREATMENTS ELIMINATING SOIL pH EFFECT

To study the effect of the various treatments segregated from the effect of pH on fruit yields, number of slips, number and weight of suckers, and on green and dry weights of plants, covariance analyses were made for each growth criterion of each experiment. Tables 8 to 13, inclusive, present the results of the covariance analyses for the Arecibo soil experiment, and certain other data to be discussed later.

It is evident from the results presented that, except for the covariance analyses of mean weight of suckers (table 13), filter press cake was the only treatment which showed either a significant or highly significant effect on the various growth criteria under consideration when soil pH was ignored. This suggests again that some effect of filter press cake other than the change it made in pH, contributed beneficially to high yield production, increase in number of slips and suckers, and high production of plant material in the Arecibo soil experiment.

The results of the covariance analyses made on the above-mentioned criteria for the Río Piedras soil experiment are also presented in tables 8 to 13, inclusive. Again filter press cake was the only treatment that

TABLE 8.—*Summary of covariance analyses for mean yield of fruits of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Adjusted mean yield of fruits	Deviations from control	Least significant deviations at—	
				5-percent level	1-percent level
	Bayamón silty clay, Palo Blanco, Arecibo				
		Pounds	*Pounds*	*Pounds*	*Pounds*
A	Soil pH adjusted with lime to 6.2	3.928	0.339	2.648	—
B	Soil pH adjusted with lime to 7.2	4.180	.591	4.528	—
C	Filter press cake mixed with soil	6.621	3.032	1.468	1.972
D	Ferrous sulfate spray applied to plants	4.235	.646	1.260	—
E	Control—no treatment	3.589	0	—	—
	Fajardo clay, Experiment Station Farm, Río Piedras				
A	Soil pH adjusted with lime to 6.2	3.769	0.783	2.473	—
B	Soil pH adjusted with lime to 7.2	3.816	.830	3.667	—
C	Filter press cake mixed with soil	5.047	2.061	1.530	2.058
D	Ferrous sulfate spray applied to plants	2.288	−.698	1.452	—
E	Control—no treatment	2.986	0	—	—

TABLE 9.—*Summary of covariance analyses for mean number of slips of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Adjusted mean number of slips	Deviations from control	Least significant deviation at 5-percent level
	Bayamón silty clay, Palo Blanco, Arecibo			
A	Soil pH adjusted with lime to 6.2	0.122	−0.055	3.740
B	Soil pH adjusted with lime to 7.2	1.861	1.684	6.396
C	Filter press cake mixed with soil	2.263	2.086	2.074
D	Ferrous sulfate spray applied to plants	.876	.699	1.780
E	Control—no treatment	.177	0	—
	Fajardo clay, Experiment Station Farm, Río Piedras			
A	Soil pH adjusted with lime to 6.2	0.580	−0.114	2.120
B	Soil pH adjusted with lime to 7.2	1.460	.766	3.130
C	Filter press cake mixed with soil	.616	− .078	1.310
D	Ferrous sulfate spray applied to plants	.051	− .643	1.190
E	Control—no treatment	−.694	0	—

TABLE 10.—*Summary of covariance analyses for mean number of suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Adjusted mean number of suckers	Deviations from control	Least significant deviation at 5-percent level
	Bayamón silty clay, Palo Blanco, Arecibo			
A	Soil pH adjusted with lime to 6.2	0.714	−1.672	1.863
B	Soil pH adjusted with lime to 7.2	.550	−1.836	3.193
C	Filter press cake mixed with soil	3.636	1.250	1.013
D	Ferrous sulfate spray applied to plants	2.112	− .274	.860
E	Control—no treatment	2.386	0	—
	Fajardo Clay, Experiment Station, Río Piedras			
A	Soil pH adjusted with lime to 6.2	1.821	1.147	1.825
B	Soil pH adjusted with lime to 7.2	2.073	1.399	2.718
C	Filter press cake mixed with soil	1.614	.940	1.106
D	Ferrous sulfate spray applied to plants	.819	.145	1.000
E	Control—no treatment	.674	0	—

TABLE 11.—*Summary of covariance analyses for mean green weight of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Adjusted mean green weight of plants	Deviations from control	Least significant deviations at—	
				5-percent level	1-percent level
	Bayamón silty clay, Palo Blanco, Arecibo				
		Pounds	*Pounds*	*Pounds*	*Pounds*
A	Soil pH adjusted with lime to 6.2	6.268	−0.689	4.965	—
B	Soil pH adjusted with lime to 7.2	6.922	− .035	8.512	—
C	Filter press cake mixed with soil	13.004	6.047	2.700	3.623
D	Ferrous sulfate spray applied to plants	6.872	− .085	2.292	—
E	Control—no treatment	6.957	0	—	—
	Fajardo clay, Experiment Station Farm, Río Piedras				
A	Soil pH adjusted with lime to 6.2	5.471	0.547	3.773	—
B	Soil pH adjusted with lime to 7.2	6.049	1.125	5.623	—
C	Filter press cake mixed with soil	8.847	3.923	2.288	3.073
D	Ferrous sulfate spray applied to plants	4.736	− .188	2.150	—
E	Control—no treatment	4.924	0	—	—

TABLE 12.—*Summary of covariance analyses for mean dry weight of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Adjusted mean dry weight of plants	Deviations from control	Least significant deviations at—	
				5-percent level	1-percent level
	Bayamón silty clay, Palo Blanco, Arecibo				
		Pounds	*Pounds*	*Pounds*	*Pounds*
A	Soil pH adjusted with lime to 6.2	2.121	.301	1.380	—
B	Soil pH adjusted with lime to 7.2	2.930	1.110	2.365	—
C	Filter press cake mixed with soil	3.709	1.889	.750	1.007
D	Ferrous sulfate spray applied to plants	1.210	−.610	.637	—
E	Control—no treatment	1.820	0	—	—
	Fajardo clay, Experiment Station Farm, Río Piedras				
A	Soil pH adjusted with lime to 6.2	1.522	0.232	1.224	—
B	Soil pH adjusted with lime to 7.2	1.692	.402	1.824	—
C	Filter press cake mixed with soil	2.571	1.281	.743	0.996
D	Ferrous sulfate spray applied to plants	1.049	−.241	.671	—
E	Control—No treatment	1.290	0	—	—

TABLE 13.—*Summary of covariance analyses for mean weight of suckers of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Adjusted mean weight of suckers	Deviations from control	Least significant deviation at 5-percent level
	Bayamón silty clay, Palo Blanco, Arecibo			
A	Soil pH adjusted with lime to 6.2	0.252	−0.899	1.492
B	Soil pH adjusted with lime to 7.2	.326	− .825	2.558
C	Filter press cake mixed with soil	1.449	− .298	.811
D	Ferrous sulfate spray applied to plants	.828	− .323	.689
E	Control—no treatment	1.151	0	—
	Fajardo clay, Experiment Station Farm, Río Piedras			
A	Soil pH adjusted with lime to 6.2	0.337	−0.148	1.128
B	Soil pH adjusted with lime to 7.2	.368	− .117	1.681
C	Filter press cake mixed with soil	.927	.442	.684
D	Ferrous sulfate spray applied to plants	.580	.095	.618
E	Control—no treatment	.485	0	—

showed either a significant or highly significant effect, but in this case only on yield and green and dry weights of plants disregarding pH effects. Once more this indicates that some factor other than pH effect contributed beneficially to favor growth criteria. Values obtained for mean number and mean weight of suckers, although not significant, were short of a significant value as compared to values needed for significance in other treatments as can be seen in tables 10 and 13, respectively.

TABLE 14.—*pH, organic matter, total nitrogen, conductivity, and available iron and manganese in treated and untreated Bayamón silty clay from Palo Blanco, Arecibo, and Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	pH at 3-inches depth	Organic matter	Total nitrogen	Conductivity, mhos × 10^{-6} at 25°C.	Available Fe	Available Mn
	Bayamón silty clay, Palo Blanco, Arecibo						
			Percent	*Percent*		*P.p.m.*	*P.p.m.*
A	Soil pH adjusted with lime to 6.2	6.16	1.5	0.18	24	0.94	9
B	Soil pH adjusted with lime to 7.2	7.29	1.5	.19	19	1.74	5
C	Filter press cake mixed with soil	4.42	4.0	.35	30	3.22	138
D	Ferrous sulfate spray applied to plants	4.80	2.0	.24	19	3.22	98
E	Control—no treatment	4.84	1.5	.25	19	3.22	96
	Fajardo clay, Experiment Station Farm, Río Piedras						
A	Soil pH adjusted with lime to 6.2	6.00	3.5	0.27	38	3.08	5
B	Soil pH adjusted with lime to 7.2	6.96	3.0	.28	32	2.41	5
C	Filter press cake mixed with soil	4.11	4.0	.60	26	8.17	41
D	Ferrous sulfate spray applied to plants	4.49	3.5	.28	20	7.64	9
E	Control—no treatment	4.56	3.5	.29	20	6.70	6

RESULTS OF SOIL pH DETERMINATIONS AND SOIL CHEMICAL ANALYSES

The results of pH determinations and chemical analyses for organic matter, total nitrogen, conductivity, and available iron and manganese for the soil subjected to the various treatments at the end of both pineapple experiments are presented in tables 14 and 15.

It is evident from the data (table 14) that the pH values for the lime-treated Arecibo soil remained practically the same at the end of 2½ years as at the beginning of the experiments. Similar results were obtained for the pH of limed soils by Bonnet et al. (3). It is also evident that filter press cake reduced soil pH as compared with the control at the end of 2½ years.

Filter press cake considerably increased soil organic matter as well as total soil nitrogen and soil conductivity. Filter press cake did not influence the available iron of the soil by the end of 2½ years. However, lime did considerably reduce the available iron of the soil. Filter press cake increased the available manganese content of the soil. On the other hand, the use of lime reduced the soil content of this element. Similar results were

TABLE 15.—*Total and soluble iron and manganese content of midsection of active center leaves of pineapple plants grown in Bayamón silty clay from Palo Blanco, Arecibo, and in Fajardo clay from Experiment Station Farm, Río Piedras*

[Ratoon crop]

Symbol	Treatments	Total Fe	Soluble Fe	Soluble iron to total Fe	Total Mn	Soluble Mn	Soluble Mn to total Mn	Ratio of Fe to Mn
	Bayamón silty clay, Palo Blanco, Arecibo							
		P.p.m.	*P.p.m.*	*Per cent*	*P.p.m.*	*P.p.m.*	*Per cent*	*Soluble*
A	Soil pH adjusted with lime to 6.2	134.38	10.58	7.87	73.05	25.13	34.40	0.42:1
B	Soil pH adjusted with lime to 7.2	127.95	5.75	4.49	58.34	27.59	47.29	.21:1
C	Filter press cake mixed with soil	144.90	28.80	19.88	94.36	33.97	36.00	.85:1
D	Ferrous sulfate spray applied to plants	118.80	9.60	8.08	153.55	44.38	28.90	.22:1
E	Control—no treatment	95.49	13.79	14.44	164.44	41.83	25.44	.33:1
	Fajardo clay, Experiment Station Farm, Río Piedras							
A	Soil pH adjusted with lime to 6.2	227.92	30.72	13.48	33.85	7.82	23.10	3.93:1
B	Soil pH adjusted with lime to 7.2	203.46	19.56	9.61	32.49	7.96	24.49	2.46:1
C	Filter press cake mixed with soil	167.07	17.87	10.70	51.93	18.36	35.35	.97:1
D	Ferrous sulfate spray applied to plants	158.85	17.75	11.17	52.53	13.64	5.97	1.30:1
E	Control—no treatment	157.77	8.07	5.12	59.01	9.10	15.42	.89:1

obtained by Bonnet et al. (2, 3). In the experiments here reported no definite relation was found between these elements in the soil and yields of pineapples. However, highest yields of pineapples were directly related to the lowest soil pH, and the highest organic-matter and nitrogen content of the soil which was produced by treatment with filter press cake.

The pH values and chemical analyses for the soil of the Río Piedras experiment are also shown in table 14. The pH values for the lime-treated soils had changed slightly at the end of 2½ years. Results were similar

to those of the Río Piedras soil experiment. As in the Arecibo soil experiment, filter press cake also reduced soil pH as compared to the control. It increased soil organic-matter to some extent and total soil nitrogen to a much more greater extent. Available iron was influenced slightly by filter press cake, but the use of lime reduced the available iron content of the soil. Filter press cake again increased the available manganese in the soil while lime slightly reduced it.

As in the Arecibo soil experiment, no definite relationship is shown between iron and manganese in the soil and yield of pineapples.

It should be noted in table 14 that the available iron was much lower than the available manganese. The available iron in the Arecibo soil was also much less than the available iron in the Río Piedras soil, while the available manganese was considerably greater in the Arecibo soil than in the Río Piedras soil. The Río Piedras soil was much higher in organic-matter content than the Arecibo soil; this different might be attributable to the fact that the Arecibo soil has been in continuous pineapple cultivation for the past 20 years, which may have helped lower its organic-matter content. On the other hand, the Río Piedras soil had been in pasture and never in pineapples.

RESULTS OF CHEMICAL ANALYSES OF LEAF TISSUE FRACTIONS

The determinations of total and soluble iron and manganese of the tissues of the fractionated active leaves of the pineapple plants of both experiments are presented in table 15. It is evident that the filter-press cake-treated plants in the Arecibo soil experiment had the highest total and soluble iron contents and the highest iron-manganese ratio as compared with plants under other treatments. Except for this one case, there was no definite relationship between the iron and manganese content of the plant tissue analyzed and yield of pineapple plants in the rest of the treatments for both the plant and ratoon crops.

Finally, there is no definite relationship between the total and soluble iron, and the manganese and corresponding ratios in the Río Piedras plant tissue analyzed and yields of pineapples.

Discussion

The information presented in this paper on plant growth, development, and production of ratoon pineapple plants supplies additional information on the beneficial effect of filter press cake on a second pineapple crop.

The qualitative observations made on plant growth and development revealed that the filter-press-cake-treated plants had a luxuriant and profuse growth which was not evident in pineapple plants undergoing other treatments. This profuse growth was to be expected since more suckers

developed in the filter-press-cake-treated plants than in plants under other treatments.

The higher yielding capacity of the filter-press-cake-treated ratoon plants as compared with that of pineapple plants under other treatments occurred because the greater number of suckers which developed from the original plant could produce more fruits. The greater number of fruits obtained from the ratoon plants under the filter-press-cake treatment as a whole did not adversely affect size or weight of fruits as compared with fruits obtained from suckers which developed under other treatments and which gave rise to a smaller number of ratoon plants. On a percentage basis filter-press-cake-treated plants produced a 40 to 45-percent increase in fruit over the control plants in both experiments, and a little more than the plants which were limed. This increase in fruit production was twice that of the plant crop for corresponding treatments (5).

The fact that control plants produced as much (a little but not significantly more) as the lime-treated plants confirms previous findings (5) that the use of lime so to control the iron-manganese ratio in the soil and in the pineapple plant as to increase fruit yields, is not a sound agricultural practice. It is suggested that lime be used only in soils deficient in calcium from intensive cultivation, or in acid soils which must be limed to raise their pH to 4.5 or 5.0 for pineapple growing.

The fruit yield of plants, suckers, and slips produced, as well as green and dry weight of plants were greater in corresponding treatments for the pineapple plants in the Bayamón silty clay soil from Arecibo than in the Fajardo clay soil from Río Piedras. This was also true of the plant crop. This might be attributed to the fact that the productivity index for the Arecibo soil has been found to be much higher, 90, than the productivity index for the Río Piedras soil which is 40 (8).

The regression studies of soil pH on the various growth criteria presented have again shown clearly that there is an inverse relationship between soil pH and fruit yields, and sucker and slip production, as well as green and dry weights of plants. In other words, increase in fruit yields as well as in the other growth criteria discussed were inversely proportional to increments in soil pH. This corroborates similar results obtained in the plant crop for yield of fruits, and slip and sucker production, and the fruit yields in pineapple field experiments (7). The fact that low soil pH, where manganese is supposed to be quite active, greatly favored plant growth, development, and production, points again to the possibility that factors other than manganese and iron adversely affect pineapple production in the Island, and that the use of lime to correct iron-manganese relationships is not wise under field conditions.

Except for one instance in the Arecibo experiment, no relationship was

found between the iron and manganese contents of plant tissues and of the soil and the yield of the pineapple plants undergoing the various treatments. In both experiments the soil analyses indicated that the highest yield of fruits and other growth criteria were related to low pH, high organic-matter, and high nitrogen content of the soil which were produced by the addition of filter press cake.

Conclusion

The outstanding beneficial effect of filter press cake and the adverse effect of lime applications to the soil as evidenced by yields of the ratoon crops of both pineapple experiments once more offers opportunities of altering or modifying agricultural practices in behalf of pineapple production in Puerto Rico.

Summary

This paper presents the results of further studies carried out to establish the relationship between iron and manganese imbalance in the soil and remedial treatments on pineapple growth, development, and production. The experimental results obtained for the ratoon crop, or second crop, are briefly summarized as follows:

1. Pineapple plants which received filter press cake in the substrate surpassed plants under all other treatments in growth and development. They were the tallest and best developed.

2. Pineapple plants grown in soil mixed with filter press cake were the heaviest yielders, their yields being significantly superior at the 1-percent level to the yields of pineapple plants under other treatments.

3. Pineapple plants grown in soil treated with filter press cake produced the greatest mean number of slips and were superior in production of suckers either significantly or highly significantly.

4. Green and dry weights of filter-press-cake-treated plants were superior in a highly significant way to the green and dry weights of plants subjected to other treatments.

5. As a whole, except for the filter-press-cake treatment, no significant differences were obtained among the pineapple plants treated otherwise with respect to yield, number of slips and suckers, and green and dry weights of plants.

6. The results of regression studies of yield of fruits, number of suckers, green and dry weights of plants on soil pH for the Arecibo soil experiment, and for number of slips and weight of suckers for the Río Piedras soil experiment, showed that those growth factors were adversely affected by increments in soil pH or increased alkalinity of the soil. Increase in soil

pH was responsible for lower fruit yields, slip and sucker production, weight of suckers, and green and dry weights of plants.

7. Disregarding soil pH effect, filter press cake was the only material producing either a significant or a highly significant effect on fruit yield, slip and sucker production, and green and dry weights of plants.

8. No definite relationship was found between iron and manganese in the soil and yield of pineapples. The highest yields were directly related to the lowest soil pH and highest organic-matter and nitrogen content of the soil from the filter-press cake treatment.

9. Except for one case, no definite relationship was found between the iron and manganese content of the plant tissue analyzed and yield of pineapples.

10. The results strengthen the assumption that factors other than iron and manganese in the soil adversely affect pineapple production in the Island, and that the use of lime to alter the iron-manganese relationships in pineapple growing is not advisable under field conditions.

11. As judged from the experimental data for both plant and ratoon crops, the use of filter press cake in conjunction with fertilizer affords an opportunity of increasing yields of pineapples, low yields being a limiting factor in the pineapple industry in Puerto Rico.

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THE APPARENT DEGENERATION OF PINEAPPLE SLIPS IN PUERTO RICO

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Introduction

One of the problems with which the pineapple growers of Puerto Rico are confronted and which merits immediate attention and solution is that of a decline in vigor of pineapple slips which lowers yields. Pineapple growers complain about the difficulty they encounter after about two-plant generations in obtaining pineapple slips of proper planting size. They attribute this to a decline in vigor or "run-down" which is said to occur when Red Spanish slips originally obtained from Cuba are grown in Puerto Rico for about two generations. The condition is serious, as it lowers yields sufficiently to menace the economic status of the pineapple growers who are obliged to import slips from Cuba, and that is expensive.

Late information obtained from Cuba by Mr. Héctor Gandía, who made a trip there last year to procure slips for Puerto Rican pineapple growers, indicates that the slips are apparently also "degenerating" there. If such is the case the problem of getting slips from Cuba will worsen in the future. Under these circumstances immediate action should be taken to find the cause of this loss of vigor or apparent "degeneration" and to devise means of improving our native stock so as to increase fruit production.

As an index of the seriousness of the problem, recent information (1)[2] indicates that production of pineapples for the 1951 crop (average plant and ratoon) amounted to 27,700 tons of fruit harvested on 3,050 cuerdas, or only 9.2 tons of fruit per cuerda.[3] This yield is considered relatively low for Puerto Rico.

Suggestions (4, 14, 15, 16) had been made that the so-called degeneration of pineapple slips might result from a nutritional derangement in the plant produced by an unfavorable balance between iron and manganese, and that this disturbance was perhaps of a more severe nature in plants developed from native[4] than in those developed from Cuban slips.[5] This

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[2] Numbers in parentheses refer to Literature Cited, p. 317.

[3] A cuerda = 0.97 acre.

[4] Native slips—slips of plants developed in Puerto Rico although planted originally with Cuban slips.

[5] Cuban slips—slips brought from Cuba and planted for the first time in Puerto Rico.

led the author to study the iron-manganese relationships in the pineapple plant under field conditions as the initial point of attack of this problem.

The yellowing of pineapple plants has been correlated with the presence of abnormally large quantities of manganese in the soil (8, 17). Later work carried out by Johnson (5, 6, 7) with yellow pineapple plants indicated that the assimilation of iron in these plants was depressed in manganiferous soils. From this, it may be inferred that the plants developed chlorosis from lack of sufficient metabolically active iron for normal chlorophyll synthesis. Since chlorosis developed earlier and to a more marked extent in the pineapple plants from native slips than in those from Cuban slips, manganese was assumed to be the main cause of such abnormal plant metabolism.

Experimental Methods

CULTURAL

With the objective mentioned, two pineapple field experiments were undertaken in the fall of 1946. The first of these was started on November 21, 1946, in the area of Palo Blanco, Arecibo, in Bayamón silty clay which had been in continuous pineapple cultivation for about 20 years. The pH of this soil was 4.94, indicating that it was relatively acid.

The second pineapple experiment was started on December 5, 1946, at the Experiment Station Farm in Fajardo clay. This soil had an average pH of 5.04, thus also being relatively acid. It had been in pasture for several years and never in pineapples.

Pineapple slips obtained directly from Cuba and native slips from a second generation were used in both experiments. The experiments followed a randomized block arrangement. Each group of pineapple slips underwent 4 different treatments, each treatment being repeated 5 times in plots of $\frac{1}{272}$ A. Each plot contained 45 slips, or a total of 225 per treatment. The treatments tried in both groups of pineapple slips or plants were as follows: 1, soil treated with calcium carbonate to raise its pH to 6.2, plus 2 iron sprays to plants; 2, soil treated with calcium carbonate to raise its pH to 6.2, plus 4 iron sprays to plants; 3, untreated soil plus 2 iron sprays to plants; and 4, untreated soil plus 4 iron sprays to plants.

The lime necessary to raise the soil pH to the required value was determined according to the method of Riera (11). The Arecibo soil required 3 tons of limestone per acre while the Río Piedras soil required 6 tons to raise the soil pH to 6.2. This indicates that the Río Piedras soil had a higher buffer capacity than the Arecibo soil, since the original pH of both was practically the same, about 5. The lime was incorporated with the top 6 inches of soil. The iron sprays consisted in applying to the plants a

solution of ferrous sulfate made by dissolving 25 pounds of the salt in 100 gallons of water.

The pineapple plants received fertilizer, formula 10[6]–6–9, at the rate of 1½ tons per acre. The fertilizer mixture was distributed in 4 applications during the growth period of the plants as is usual in commercial plantings.

To force blooming, the pineapple plants of the Arecibo experiment were acetylene treated on January 30, 1948, 14 months after planting, while those of the Río Piedras experiment received their acetylene treatment on February 12, 1948, also 14 months after planting. The experiments were harvested on June and July 1948, respectively.

Leaf samples were taken from each replicated plot undergoing each treatment in both experiments for quantitative chemical determinations of total and soluble iron and manganese in the meristematic tissue of the leaves. Fifteen leaves were taken from 15 plants chosen at random from the 45 plants in each replicated plot. The active or largest leaf of each plant was selected for this purpose (2). The procedure followed for preparing the leaf samples for chemical analyses was practically the same as explained earlier (2).

Method of Analyses

To digest the ground leaf-tissue samples for determination of total iron and manganese the procedure described in a previous paper (2) was used. Iron was determined by the Saywell and Cunningham orthophenanthroline method (13), while manganese was determined according to the periodate method of Peech (9) using a Coleman spectrophotometer model 14.

The procedure explained earlier (2) was used for determinations of soluble iron and manganese in the leaf-tissue fractions.

Experiments at Palo Blanco, Arecibo

Growth of plants undergoing various treatments

During the course of the experiments it was observed that the pineapple plants from native slips made as good growth as those from Cuban slips. However, the plants from Cuban slips looked stockier and occupied somewhat more lateral space than those from native slips, which, on the other hand, tended to be slender and taller. No difference was noted in any individuals of the two groups of plants which could be attributed to lime or iron spray treatments. In other words, plants in unlimed plots made as good growth as plants in limed plots, while plants which received 2 iron sprays made as good growth and were as green as those which received 4.

[6] As ammonia (NH_3).

EFFECT OF TREATMENTS ON YIELDS—PLANT CROP

The yield of the pineapple plants for the plant crop in the Arecibo experiment are presented in table 1, which also shows the evaluation of the statistical significance of the yield data as a result of treatments. It is clear that the pineapple plants from native slips were superior in production either at the 5- or 1-percent level to those from Cuban slips.

The partition of the treatment sum of squares into their component parts indicated that differences in source of slips affected fruit yields in a

TABLE 1.—*Yield of pineapple plants developed from native and Cuban slips in Bayamón silty clay at Palo Blanco, Arecibo*

[Plant and ratoon crops, 1948–49]

Treatments	Plant crop[1]			Ratoon crop, yield per acre
	Yield per acre	Outyielded at—		
		5-percent level	1-percent level	
	Tons			*Tons*
1. Plants from native slips, limed, 2 iron sprays	22.28	7	5, 6, 8	22.82
2. Plants from native slips, limed, 4 iron sprays	20.76	—	—	21.54
3. Plants from native slips, not limed, 2 iron sprays	21.55	6	5, 8	24.13
4. Plants from native slips, not limed, 4 iron sprays	21.19	5, 8	—	23.26
5. Plants from Cuban slips, limed, 2 iron sprays	18.80	—	—	23.12
6. Plants from Cuban slips, limed, 4 iron sprays	19.11	—	—	22.66
7. Plants from Cuban slips, not limed, 2 iron sprays	19.72	—	—	24.18
8. Plants from Cuban slips, not limed, 4 iron sprays	18.80	—	—	22.25

[1] Least significant difference between mean yields at the 5-percent level, 2.00 tons; at the 1-percent level, 2.70 tons.

highly significant way and had no significant interaction with any of the other treatments (table 2). It was apparent that plants from native slips produced significantly more than those from Cuban slips. On the other hand, neither lime nor iron spray treatments had any significant effect on the yield of the plant crop.

RESULTS OF CHEMICAL ANALYSES OF LEAF-TISSUE FRACTIONS

The data for the determinations of total and soluble iron and manganese in the meristematic tissue of the active leaves analyzed for the plant

crop are presented in table 3. In order to find out whether there was any relation between leaf-tissue contents of soluble iron and manganese and yield, a covariance analyses was made. The results showed a highly significant difference between sources of slips even after eliminating the effects of the tissue contents of soluble iron and manganese on yield, indi-

TABLE 2.—*Statistical analysis showing the partition of treatment sum of squares of deviations of fruit yields into main effects and interactions, Arecibo experiment*

[Plant and ratoon crops, 1948–49]

Source main factors	Degrees of freedom	Sum of squares	Variance	*F* value[1]
Plant crop				
Treatments:	7	1.6433		
Source of slips	1	1.4400	1.4400	22.61**
Lime	1	.0110	.0110	0.17
Iron	1	.1000	.1000	1.57
First order interactions:				
Source of slips x lime	1	0	0	0
Source of slips x iron		0	0	0
Lime x iron	1	0	0	0
Second order interaction:				
Source of slips x lime x iron	1	.0923	.0923	1.45
Error	28	1.7841	.0637	
Ratoon crop				
Treatments:	7	1,508.37		
Source of slips	1	7.20	7.20	0.01
Lime	1	455.70	455.70	.51
Iron	1	697.20	697.20	.78
First order interactions:				
Source of slips x lime	1	189.70	189.70	.21
Source of slips x iron	1	2.10	2.10	.002
Lime x iron	1	938.00	938.00	.04
Second order interaction:				
Source of slips x lime x iron	1	118.97	118.97	.13
Error	28	25,062.25	895.08	

[1] One asterisk indicates significance, two asterisks high significance in this and later tables.

cating thereby no evidence of a definite trend with respect to these elements in the plant tissue analyzed and yield of pineapple plants undergoing the various treatments.

EFFECT OF TREATMENTS ON YIELDS—RATOON CROP

The statistical analysis of the yield data for the ratoon crop presented in table 1 indicate that there were no significant differences between yields produced by plants from the two kinds of slips undergoing the various

treatments. No significant yield differences were obtained which could be attributed to any of the source of slips, lime, or iron sprays (table 2). Contrary to expectations the experimental results presented for both plant and ratoon crops point to the fact that plants from native slips were

TABLE 3.—*Total and soluble iron and manganese content of meristematic tissue of active leaves of pineapple plants developed from native and Cuban slips in Bayamón silty clay at Palo Blanco, Arecibo*

[Plant and ratoon crops—1948–49]

Treatments	Total iron	Soluble iron	Total manganese	Soluble manganese	Ratio Fe/Mn
Plant crop					
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*	*Soluble*
1. Plants from native slips, limed, 2 iron sprays	351	63	1006	166	0.50:1
2. Plants from native slips, limed, 4 iron sprays	324	145	676	661	.22:1
3. Plants from native slips, not limed, 2 iron sprays	252	58	902	289	.20:1
4. Plants from native slips, not limed, 4 iron sprays	312	124	1448	1085	.11:1
5. Plants from Cuban slips, limed, 2 iron sprays	828	485	430	260	1.80:1
6. Plants from Cuban slips, limed, 4 iron sprays	651	450	553	326	1.38:1
7. Plants from Cuban slips, not limed, 2 iron sprays	469	133	128	102	1.30:1
8. Plants from Cuban slips, not limed, 4 iron sprays	540	150	—	—	—
Ratoon crop					
1. Plants from native slips, limed, 2 iron sprays	201	68	840	544	0.13:1
2. Plants from native slips, limed, 4 iron sprays	140	15	510	253	.06:1
3. Plants from native slips, not limed, 2 iron sprays	254	67	930	632	.11:1
4. Plants from native slips, not limed, 4 iron sprays	166	66	810	552	.12:1
5. Plants from Cuban slips, limed, 2 iron sprays	140	27	690	473	.06:1
6. Plants from Cuban slips, limed, 4 iron sprays	88	56	810	494	.11:1
7. Plants from Cuban slips, not limed, 2 iron sprays	114	50	780	416	.12:1
8. Plants from Cuban slips, not limed, 4 iron sprays	114	19	870	485	.04:1

either significantly superior or equal in production to plants from Cuban slips. This point will be considered in the discussion.

RESULTS OF CHEMICAL ANALYSES OF LEAF-TISSUE FRACTIONS

Table 3 reports also the iron and manganese contents, both total and soluble, of the meristematic tissue of active leaves of the pineapple plants

undergoing the various treatments. Again, for the ratoon crop, the analyses of covariance indicated no conclusive evidence of a definite relation between the elements iron and manganese in the leaf-tissue samples and fruit production.

Experiments at Experiment Station Farm, Rio Piedras

GROWTH OF PLANTS UNDERGOING VARIOUS TREATMENTS

Similar results were obtained with respect to plant growth at Río Piedras as at Arecibo. However, irrespective of treatments and kind of slip, the plants of the Arecibo experiment made better growth than those at Río

TABLE 4.—*Yield of pineapple plants developed from native and Cuban slips in Fajardo clay at Experiment Station Farm, Rio Piedras*

[Plant and ratoon crops—1948–49]

Treatments	Plant crop[1]		Ratoon crop[2]		
	Yield per acre	Outyielded at 5-percent level	Yield per acre	Outyielded at—	
				5-percent level	1-percent level
	Tons		*Tons*		
1. Plants from native slips, limed, 2 iron sprays	18.74	—	10.59	—	—
2. Plants from native slips, limed, 4 iron sprays	18.98	—	8.27	—	—
3. Plants from native slips, not limed, 2 iron sprays	17.33	—	11.08	—	—
4. Plants from native slips, not limed, 4 iron sprays	20.02	—	13.76	1, 6	2
5. Plants from Cuban slips, limed, 2 iron sprays	19.41	—	11.25	—	—
6. Plants from Cuban slips, limed, 4 iron sprays	19.72	—	10.53	—	—
7. Plants from Cuban slips, not limed, 2 iron sprays	21.98	3	11.75	2	—
8. Plants from Cuban slips, not limed, 4 iron sprays	20.57	—	13.00	—	2

[1] Least significant difference between yields at the 5-percent level, 3.47 tons.

[2] Least significant difference between yields at the 5-percent level, 3.10 tons; at the 1-percent level, 4.18 tons.

Piedras. One factor which might have contributed to this difference in vegetative growth is the productivity index of the soils, which is much higher for the Bayamón silty clay of Arecibo than for the Fajardo clay of Río Piedras (12).

EFFECT OF TREATMENTS ON FRUIT YIELDS—PLANT CROP

Table 4 reports the yield data in tons of fruit per acre for the plant crop. Contrary to the Arecibo plant-crop experiment, the statistical analyses of the yield data indicated that the experiment in itself was not significant,

since the F value for the experiment was 1.31, as compared to an F value of 2.36 required for odds of 19:1. In spite of this, treatment 7 (plants from Cuban slips, not limed, 2 iron sprays) surpassed treatment 3 (plants from native slips, not limed, 2 iron sprays) in production at the 5-percent

TABLE 5.—*Statistical analysis showing the partition of treatment sum of squares of deviations of fruit yields into main effects and interactions, Río Piedras experiment*

[Plant and ratoon crops, 1948–49]

Source, main factors	Degrees of freedom[1]	Sum of squares	Variance	F value
Plant crop				
Treatments	7	1.7563	.2509	1.31
Source of slips	1	.7343	.7343	3.84
Lime	1	.1488	.1488	.78
Iron	1	.0547	.0547	.29
First order interactions				
Source of slips x lime	1	.2496	.2496	1.30
Source of slips x iron	1	.2690	.2690	1.41
Lime x iron	1	.0072	.0072	.04
Second order interactions				
Source of slips x lime x iron	1	.2927	.2927	1.53
Error	27	5.1668	.1914	
Ratoon crop				
Treatments	7	5,324.05		
Source of slips	1	288.37	288.37	.94
Lime	1	2,785.56	2,785.56	9.06**
Iron	1	31.68	31.68	.10
First order interactions				
Source of slips x lime	1	326.05	326.05	1.06
Source of slips x iron	1	.20	.20	0
Lime x iron	1	1,602.77	1,602.77	5.21*
Second order interactions				
Source of slips x lime x iron	1	289.42	289.42	.94
Error	27	8,306.98	307.67	

[1] Number of degrees of freedom for error reduced by one because of a missing observation.

level. This significant difference should be taken as chance and not as conclusive since, as mentioned above, the experiment was not significant. In synthesis, there was no difference between the plants from native slips and those from Cuban slips when under corresponding treatments. Obviously no significant yield differences were found which could be attributed to source of slips, lime, or iron sprays (table 5).

RESULTS OF CHEMICAL ANALYSES OF LEAF-TISSUE FRACTIONS

Table 6 presents the results of quantitative chemical determinations of total and soluble iron and manganese in the meristematic tissue of active leaves analyzed for the plant crop. The results of the covariance analyses showed no definite relation between the contents of iron and manganese in the plant tissue analyzed and yield of pineapples. It can

TABLE 6.—*Total and soluble iron and manganese content of meristematic tissue of active leaves of pineapple plants developed from native and Cuban slips in Fajardo clay at Experiment Station Farm, Río Piedras*

[Plant and ratoon crops—1948–49]

Treatments	Total iron	Soluble iron	Total manganese	Soluble manganese	Ratio Fe/Mn
Plant crop					
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*	*Soluble*
1. Plants from native slips, limed, 2 iron sprays	150	64	32	0	—
2. Plants from native slips, limed, 4 iron sprays	140	99	47	44	2.25:1
3. Plants from native slips, not limed, 2 iron sprays	37	9	3	3	3.00:1
4. Plants from native slips, not limed, 4 iron sprays	30	6	3	2	3.00:1
5. Plants from Cuban slips, limed, 2 iron sprays	248	115	79	115	1.00:1
6. Plants from Cuban slips, limed, 4 iron sprays	273	99	0	0	—
7. Plants from Cuban slips, not limed, 2 iron sprays	11	27	2	2	13.50:1
8. Plants from Cuban slips, not limed, 4 iron sprays	5	26	2	0	—
Ratoon crop					
1. Plants from native slips, limed, 2 iron sprays	210	30	180	116	0.26:1
2. Plants from native slips, limed, 4 iron sprays	210	68	90	53	1.28:1
3. Plants from native slips, not limed, 2 iron sprays	193	9	270	85	.11:1
4. Plants from native slips, not limed, 4 iron sprays	149	11	180	86	.13:1
5. Plants from Cuban slips, limed, 2 iron sprays	245	53	240	206	.26:1
6. Plants from Cuban slips, limed, 4 iron sprays	210	17	60	39	.44:1
7. Plants from Cuban slips, not limed, 2 iron sprays	210	52	210	116	.45:1
8. Plants from Cuban slips, not limed, 4 iron sprays	374	205	60	18	11.40:1

be seen from table 6 that treatments 2 and 5 show a high concentration of total and soluble manganese in relation to the other treatments, but there is no explainable reason for this variation at the present time.

EFFECTS OF TREATMENTS ON FRUIT YIELDS—RATOON CROP

The yield data for the ratoon plants which underwent the different treatments are presented also in table 4. The results of the evaluation of

the statistical significance of the yield differences that may be attributed to treatment effect appear in the same table. It is evident that, irrespective of iron sprays, either native or Cuban plants grown in unlimed soils produced significantly more at the 5- or 1-percent level than similar plants on limed soils.

The low production of the ratoon crop in this case must be attributed to competition of grasses and weeds with the pineapple plants, it having been impossible to cultivate the soil because of intermittent heavy rains for several months. Otherwise it is logical to assume that under normal weather conditions, as was the case for the Arecibo ratoon crop, the yields would have been equal to, if not higher than, the yields of the plant crop.

To find what influence, if any, treatment components and their corresponding interactions had on yields of the ratoon crops, a statistical analysis was made of the yield data with respect to source of slips, lime, and iron sprays, a summary of which is shown in table 5. The partition of the treatment sum of squares into their component parts indicated that neither source of slips nor iron sprays were important. However, the use of lime was detrimental to yield in a highly significant way, as is evident in the data presented in table 4. Similar results were obtained by Pennock and Hernández on the use of lime and the production of pineapple plants (2, 3, 10).

RESULTS OF CHEMICAL ANALYSES OF LEAF-TISSUE FRACTIONS

The results of the total and soluble iron and manganese determinations in the plant tissue of the ratoon plants analyzed are presented in table 6. As with these same treatments in the ratoon plants of the Arecibo experiment, no significant relation was found between yield and iron and manganese in the leaf fractions analyzed.

Summing up the results presented thus far for both plant and ratoon crops in both the Arecibo and Río Piedras experiments, it may be said that pineapple plants from native slips were either superior or equal in fruit production to pineapple plants from Cuban slips. Moreover, no conclusive evidence was obtained which could explain variations in the production of pineapple plants on the basis of iron and manganese contents of the plant tissue analyzed.

Additional Experiments

To continue the studies on the apparent "run-down" or "degeneration" of the Cuban slips in the second generation, and to find out whether the condition occurred there, additional experiments were begun in the same localities where the previous experiments were carried on—that is, at Palo Blanco, Arecibo, and at the Experiment Station Farm at Río Piedras.

They were planted in the same type of soils. The Arecibo experiment was planted on September 30, 1948, while the Río Piedras experiment was planted on January 21, 1951.

The pineapple plants in both of these experiments developed from slips obtained from the plants of the plant-crop experiments established for the first time in 1946 with native and Cuban slips. The same treatments were used for each group of slips as for the experiments previously reported. However, the number of replications per treatment was increased from

TABLE 7.—*Yield of pineapple plants developed from native and Cuban slips obtained from the plant-crop experiments at Palo Blanco, Arecibo, and Experiment Station Farm at Río Piedras established in 1946*

Treatments	Plant crop of Arecibo: Yield per acre	Plant crop of Río Piedras		
		Yield per acre	Outyielded at[1]—	
			5-percent level	1-percent level
	Tons	*Tons*		
1. Plants from native slips, limed, 2 iron sprays	10.59	7.35	—	—
2. Plants from native slips, limed, 4 iron sprays	11.70	6.98	—	—
3. Plants from native slips, not limed, 2 iron sprays	9.92	8.33	—	5
4. Plants from native slips, not limed, 4 iron sprays	11.14	9.37	6	1, 2, 5
5. Plants from Cuban slips, limed, 2 iron sprays	9.74	6.12	—	—
6. Plants from Cuban slips, limed, 4 iron sprays	12.06	7.78	5	—
7. Plants from Cuban slips, not limed, 2 iron sprays	9.37	8.51	2	5
8. Plants from Cuban slips not limed, 4 iron sprays	9.67	8.08	5	—

[1] Least significant difference between yields at the 5-percent level, 1.49 tons; at the 1-percent level, 2.01 tons.

5 to 6 in the Arecibo experiment only. Similar procedures were followed for setting up the experiments, fertilizing the plants, and collecting and preparing leaf samples for chemical analyses. The same methods of analyses were used for determination of total and soluble iron and manganese.

The plants of both experiments were acetylene treated on December 5, 1949, and February 1950 respectively, and were harvested on May and June, and July and August, respectively. Since only a plant crop was harvested from each experiment, the results of both will be considered together.

GROWTH OF PLANTS UNDERGOING VARIOUS TREATMENTS

During the course of the experiments it was noted that growth of the plants, both from native and Cuban slips, was not as good as that of plants in the first experiments. Vegetative growth was less, as evidenced

TABLE 8.—*Statistical analysis showing the partition of treatment sum of squares of deviations of fruit yields into main effects and interactions, Arecibo and Río Piedras experiments*

[Plant crop]

Source main factors	Degrees of freedom	Sum of squares	Variance	*F* value
Arecibo experiment				
Treatments	7	1.1582		
Source of slips	1	.1365	0.1365	0.6900
Lime	1	.3169	.3169	1.6021
Iron	1	.5002	.5002	2.5280
First order interactions				
Source of slips x lime	1	.0420	.0420	.2123
Source of slips x iron	1	.0015	.0015	.0076
Lime x iron	1	.0675	.0675	.3412
Second order interactions				
Source of slips x lime x iron	1	0.0936	.0936	.4732
Error	35	6.7115	.1978	
Río Pedras experiment				
Treatments	7	0.9275		
Source of slips	1	.0384	0.0384	1.0847
Lime	1	.6150	.6150	17.37**
Iron	1	.0563	.0563	1.5903
First order interactions				
Source of slips x lime	1	.0062	.0062	.1751
Source of slips x iron	1	.0047	.0047	.1327
Lime x iron	1	.0077	.0077	.2175
Second order interaction				
Source of slips x lime x iron	1	.1992	.1992	5.63*
Error	28	.9911	.0354	

by height and less profuse development of plants. There was a general tendency for the plants to be rather slender, this condition being more pronounced in those resulting from native slips than in the plants from Cuban slips. In the Río Piedras experiment growth was more depressed, especially in the lime-treated plants of both groups of slips, as compared with the unlimed plants. This seemed to indicate that lime was detrimental to plant growth and consequently to production, as will be shown later.

EFFECT OF TREATMENTS ON YIELDS

Table 7 reports the yield from the pineapple plants which underwent treatment in the Arecibo and Río Piedras experiments. The results of the evaluation of the statistical significance of the yield differences between the treatments in the Arecibo experiment indicated that there was no significant difference between the yields of the two types of plants undergoing corresponding treatments. In other words, plants developed from native slips yielded as heavily as plants from Cuban slips. The results were similar to those obtained for the ratoon crop of the Arecibo experiment already reported, in which no significant differences in yield were obtained which could be attributed to source of slips, lime applications, or iron sprays (table 8).

The striking fact brought out by the yield data of the Río Piedras experiment (table 7) is that unlimed plants from both native and Cuban slips yielded significantly better at the 5- or 1-percent level than plants grown in soil that received lime applications.

The partition of the treatment sum of squares into their component parts indicated that neither source of slips nor iron sprays affected fruit yields. On the other hand, lime affected fruit yields adversely in a highly significant way (table 8). Thus lime was detrimental to the production of pineapple plants, as was pointed out in discussing the yield data presented in table 8 for the Río Piedras experiment.

DISCUSSION

The yield data obtained in the first set of the 1946 experiments demonstrated that plants from native slips produced significantly more than or as well as plants from Cuban slips. Growers believe that plants from native slips produce less, since they claim that plants from Cuban slips, which have been planted in the Island for two or three generations, produce considerably less than plants from such slips when planted for the first time in the Island. Thus, there seems to be a sort of contradiction between the growers' views and our first experimental results. However, the results of the statistical analyses of treatment components (source of slips, lime, and iron sprays) indicated, at least for the plant crop of the Arecibo experiment, that difference in the source of slips affected yields in a highly significant way, but had no significant interaction with any of the other treatments. In the Río Piedras experiments the source of slip had no significant effect, which indicated that native slips were as good as the Cuban. Hence, a possible explanation for obtaining significantly higher yields, or as good yields, with native as with Cuban slips is that the native slips used in these experiments, although having being planted

in Puerto Rico for two generations, had for some reason either a higher or as good vigor as the Cuban slips.

When yields of the plant crop in the second set of experiments are considered (experiments established with slips obtained from the plants of the first experiments set up in 1946) it is evident that there was quite a reduction in yields as compared to those of the first plant-crop experiments. This was true for pineapple plants from both native and Cuban slips. In fact, it was not possible to obtain slips of proper size for future plantings. Contrary to the first case, these results accord with the pineapple growers' view in that pineapple production, and consequently the obtaining of good slips for future plantings, declines as pineapple plantings are continued on the same sites. However, these results, and others that have been presented in this paper, do not show that the apparent "degeneration" or "run-down" of pineapple slips which result in low production result from an unfavorable balance of iron and manganese in the pineapple plant adversely affecting its normal metabolism.

The nonbeneficial effect or detrimental effect of lime on yields in the experiments discussed, which confirm previous findings (2, 3, 10), plus the ineffectiveness of iron sprays, in addition to the lack of relationship between the tissue contents of iron and manganese in the pineapple plants and their production, all tend to strengthen the assumption that factors other than iron and manganese are responsible for loss of vigor of pineapple slips and consequent progressively lower yields of pineapples in Puerto Rico. Moreover, the fact that significantly lower yields were obtained from plants in limed soils than from those in unlimed soils (approximate pH of 5), wherein manganese is supposed to be quite active, strongly suggests that factors other than iron-manganese relationships adversely affect pineapple production.

We believe, however, that the apparent "degeneration" or "run-down" of pineapple slips might be attributed in part to unfavorable changes brought about in the soil as a result of present agricultural practices. If these could be modified in some respects, it should be possible to obtain pineapple slips of uniform and adequate size, weight, and vigor to produce good fruit yields for several years. For example, lime should be applied to only those pineapple soils which require this amendment to raise the pH to 4.5 or 5.0 for optimum production of pineapples, or to soils that have been so intensively cultivated that there is need of this material to supply the plants with the calcium necessary for normal metabolism. The use of filter press cake offers great potentialities for increasing the yield of pineapples (2, 3). These agricultural practices together with others which might contribute not only to increased yields but also to the production of healthy pineapple slips of proper planting size, should be put into

practice. In this way it would be possible to obtain good fruit yields and good planting material for the years following.

Conclusion

The ineffectiveness of iron sprays to pineapple plants, plus the nonbeneficial or detrimental effect of lime applications to pineapple soils, in addition to the lack of relationship between quantitative chemical analyses for both total and soluble iron and manganese in the pineapple plant tissue and yields, point to the possibility that factors other than iron and manganese may be responsible for the apparent "degeneration" of pineapple slips and consequent lowered fruit yields. Therefore, the apparent "degeneration" of pineapple slips should be considered from other angles and no longer as a result of iron-manganese relationships in the soil and in the plant.

Summary

Pineapple experiments were carried on using imported Cuban slips and native slips with the object of investigating the apparent "degeneration" of slips. The suggestion that this apparent "degeneration" of slips might result from a nutritional derangement produced by an unfavorable balance of iron and manganese that was more severe in the plants developed from native slips, and resulted in a more marked chlorosis than in the plants developed from Cuban slips, led to studies of iron-manganese relationships in the pineapple plant under field conditions as the initial point of attack on this problem.

Cuban as well as native slips were planted in untreated soil and in soil which received calcium carbonate as ordinarily applied by pineapple growers to control manganese in the soil. In addition, the plants which developed from each group of slips received either 2 or 4 iron sprays; the purpose was to find out which spray procedure was best. The experimental data from the various experiments may be summarized as follows:

1. Pineapple plants from native slips were either superior or equal in production to those developed from Cuban slips. This was true for both plant and ratoon crops.

2. The use of lime was either nonbeneficial or detrimental to yields of pineapples.

3. No significant yield differences were found whether 2 or 4 iron sprays were applied to the plants.

4. Similar results were obtained both with respect to yields and to the use of lime and iron sprays in later experiments with slips obtained from the plants of the first plant-crop experiments.

5. The yields obtained in the plant crop of the later experiments were considerably less than those from the first plant-crop experiments. This

was true for both native and Cuban plants. It also accords with the pineapple growers' view that pineapple production, and consequently the obtaining of good slips for future plantings, declines when pineapple plantings are long continued on the same sites.

6. No relationship was found between the soluble iron and manganese in the plant tissue analyzed and yields of pineapples. This suggests that factors other than iron and manganese may be responsible for the apparent "degeneration" or loss of vigor of pineapple slips which is reflected in low yields.

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